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A COST-BENEFIT EVALUATION OF THE LANDSAT FOLLOW-ON PROGRAM

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FINAL

A COST-BENEFIT EVALUATION
OF THE
LANDSAT FOLLOW-ON PROGRAM

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Office of Applications

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NOTE OF TRANSMITTAL

This report has been prepared for the National Aeronautics and Space Administration, Office of Applications, under Contract NASW-2558.

It represents the combined inputs of ECON, Inc. and the Office of Applications, based on analytical work performed by both organizations. More detailed working papers, documentation, and/or reports lie behind each of the chapters of this report.

ECON wishes to acknowledge the work of Klaus Heiss, John Andrews, George Hazelrigg, Keith Lietzke, Francis Sand and others of the ECON staff, along with the contributions C. Buffalano, M. Rosenzweig, V. Salemenson, N. Short, and others of the Office of Applications staff.

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1. INTRODUCTION AND SUMMARY

This volume presents the results of a benefit and cost study for the LANDSAT Follow-on system with a Thematic Mapper. The analysis shows that the present worth of the benefits exceeds the present worth of the costs by a factor between 6.5 and 13 using a 10 percent discount rate and an infinite horizon for both.

Although uses and applications of LANDSAT technology continue to grow, as is characteristic of successful technology in its introductory phases, this study focuses only on major, demonstrated applications, conservatively evaluated. No benefits have been included except where a definite need for the information has been shown, a mechanism for disseminating the information has been defined, a technical capability has been demonstrated, and a defendable method of evaluating the economic worth has been developed. This approach has meant that certain applications with definite promise and substantial likely benefits could not be evaluated or assigned any benefits. Mention is made of these areas, however, either in the appropriate subject chapter or in the final chapter on "Non-Quantified Benefits".

The major benefit areas foreseen for the baseline global LANDSAT Follow-on with a Thematic Mapper are summarized in Table 1.1. Benefits total 500-1000 million annually.

Agriculture. Improved production and distribution of crops would be made possible by improved forecasts of world crop production. Estimated annual benefits, by 1985, are \$336 to a potential \$581 million/year.

Oil and Mineral Exploration. The benefits result from exploration cost savings to United States producers. Annual benefits are estimated at

Table 1.1 Annual Benefits of LANDSAT Follow-on (Fiscal Year 1976 Millions of Dollars)

	Estimated Annual Benefits
Agricultural Crop Information	336-581
Petroleum-Mineral Exploration	42
Hydrologic Land Use	22
Water Resources Management	13-41
Forestry	7
Land Use Planning and Monitoring	15-48
Soil Management	5-9
Total (rounded)	440-750

42 million/year. Further, but non-quantified benefits are derivable from enrichment of the prospect mix, and from effects on the world petroleum markets.

Hydrologic Land Use. By providing cheaper surface cover maps, annual cost savings exceeding $22 million would be possible within the federal agencies and the regional, local, and special purpose water resource programs studied. In many cases, these benefits could be re-invested in extending or improving the work of the agencies involved, resulting in some further benefit which has not been included in the estimates.

Water Resources Management. Annual benefits of $13 to $42 million from more irrigation water and hydropower are expected based on improved management of impounded water due to better information on river basin snow cover.

Forestry. Annual benefits of at least $7 million are forecast by using LANDSAT information to improve Forest Service timber inventories and then using this improved inventory data to make better tree planting and harvesting decisions.

Land Use Planning. Annual benefits of $15 to $48 million are estimated, based on the cost of obtaining equivalent planning data by the best alternative means, an aircraft-borne surveillance system. This estimate is based on estimates of the data requirements of federal, state, and regional agencies not included in the agriculture, oil-mineral exploration, water resources, forestry or soil management applications.

Soil Management. Annual benefits of $5 to $8 million are estimated from cost savings in the preparation of soil base maps. Further benefits from detecting soil loss or nutrient deficiencies are identified but not quantified.

The cost of an operational LANDSAT Follow-On system is discussed in detail in the System Design Document but the results are summarized in Table 1.2. The space system flight cost includes the spacecraft, telemetry, command and control, maintenance of the system in operational status, shuttle servicing, and refurbishment. The Space System ground data costs include processing data to the point where an archival tape is prepared. The unique user costs include special processing of the archival tape to obtain management information. A special effort has been made to assure that unique user costs are for the same data product that enters into the benefit calculations. The EROS Data Center is expected to fill the needs of all but the agriculture and water management community.

The rate of adoption of LANDSAT technology, and hence the rate of achieving the potential annual benefits, is difficult to estimate with confidence. We have assumed that 50 percent of the estimated potential benefits will be achieved within the first year that the LANDSAT system becomes available; 80 percent of the potential benefits will be achieved three years after the system becomes available, and 95 percent of the potential benefits obtained three years after that. This is shown schematically in Figure 1.1.

In order to relate the benefits of the LANDSAT Follow-on system to the costs, we compare the present value of the benefits and costs. All benefits and costs are computed in FY 1976 dollars and a discount rate of 10 percent is applied. This choice of discount rate is based on the guidelines of OMB Circular A-76. An infinite time horizon is employed in this study. Table 1.3 shows the present value of the costs and benefits in Tables 1.1 and 1.2. Based on these values the LANDSAT Follow-On system has a benefit/cost ratio of 10 to 20.

Table 1.2 Base Line System Costs ($ Millions)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991 . . .	Present Worth
Space System												
Capital	177		47									$179
Recurring				24			24			24[1]		
Ground System												
Capital	34.4										24.4[2]	78.6
Recurring	7	7	7	7	7	7	7	7	7	7	7[3]	
User Unique												
Capital	27.1										19.2[2]	184.8
Recurring	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5[3]	
TOTAL												$442.4

[1] Repeats every three years.
[2] Repeats every ten years.
[3] Repeats yearly.
[4] Includes Agriculture, Hydrologic Land Use, EROS Data Center.

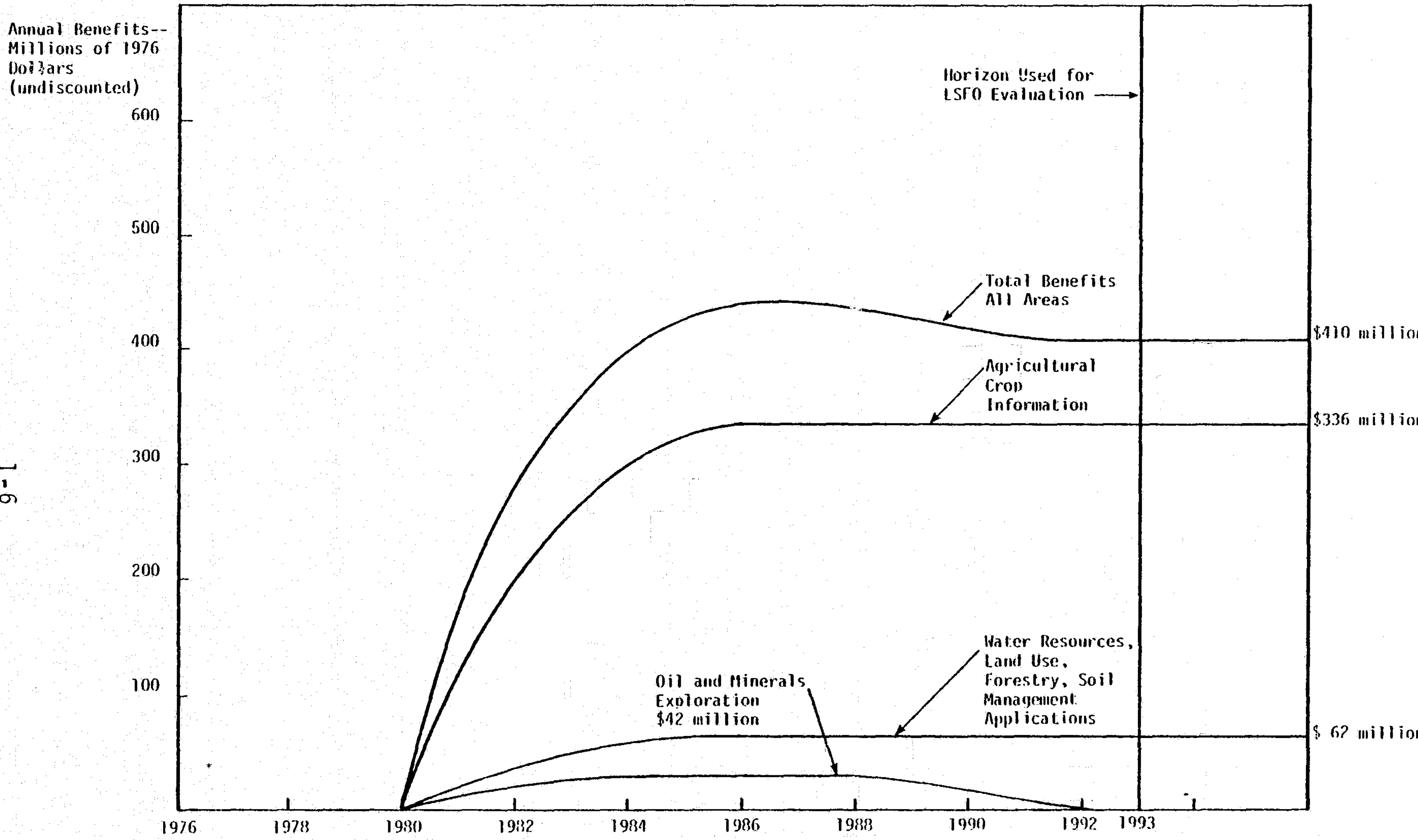

Figure 1.1 Benefit Stream of LANDSAT Follow-on System with the Thematic Mapper. (using lower estimates)

(ECON version)

Table 1.3 Present Value of the Benefits and Costs of the LANDSAT Follow-on System, 1980-1993 Period ECON Benefit and Cost Estimates (Discounted at 10%)

	Benefit ($ Million)	Cost ($ Million)
Space System	--	257
Agricultural Crop Information	1950-3370	54
Hydrologic Land Use	127	10
Petroleum-Mineral Exploration	245	120
Water Resources Management	75-237	
Forestry	41	
Land Use Planning-Monitoring	87-278	
Soil Management	29-52	
TOTAL	2555-4350	441

2. SYSTEM COSTS

2.1 Introduction

The Baseline System consists of a Space Segment and a Ground Data Management System. Design details can be found in the Systems Design Report for the LANDSAT follow-on.

The spacecraft orbits at 705 km and there is one satellite in orbit at all times which results in 18-day coverage. The space segment is designed to minimize costs by utilizing shuttle retrieval and spacecraft refurbishment. The Ground Data Management System uses the Tracking and Data Satellite System to provide worldwide data to a central location. The data is processed to produce an archival data tape which is further processed by individual users to produce valuable information.

2.2 Space Segment Costs

The Space Segment for the Baseline System has capital costs in 1981 and 1983 and recurring costs beginning in 1984 which repeat once every three years as shown in Table 2.1. The 1981 capital costs are actually spent between 1977 and 1981 but are shown aggregated into a 1981 total. They include the:

1. Design of the system
2. Two instruments--the Multi-Spectral Scanner (MSS) and the Thematic Mapper (TM)
3. The Multi-Mission Spacecraft (MMS)
4. Mission-unique hardware such as the solar array and the TDRS antenna
5. Three MMS module spares
6. Two launch vehicles.

The 1983 capital cost is for a second spacecraft and supporting hardware. However, it does not include the cost of another launch vehicle. The recurring cost includes a shuttle launch of the second spacecraft in 1984 and the retrieval of the first spacecraft. Thirty percent of the cost of the space hardware is also included for refurbishment of the first spacecraft. Retrieval and refurbishment continue every three years thereafter. These costs are based on sharing the shuttle launch with another program.

The present worth of the Space Segment cost stream, discounted at 10 percent, is $179M.

2.3 Ground Data Management System

The Ground Data Management System is the complete data system which provides timely data dissemination to meet the user needs. Care has been taken to make the data processing costs consistent with the information requirements which produce the benefits shown in Table 2.1.

The Ground System's 1981 capital cost is for the data processing from TDRS output to archival tape. Included are the:

1. Operations Control Center
2. Central Data Processing Facility
3. Product Generation and Distribution Facility
4. Archive Facility
5. Data Input System
6. Data Management Unit
7. System Engineering
8. Modifications to the Goddard direct readout station to receive Thematic Mapper data.

The subsequent capital costs are approximately 70 percent of the initial capital cost and repeat every ten years. These are for the refurbishment

Table 2.1 Base Line System Costs ($ Millions)

							Present Worth
SPACE SEGMENT							179
	Year:	81	83	84	87	90	
Capital		177	47				
Recurring				24	24	24	
GROUND DATA MANAGEMENT SYSTEM							263
Ground System	Year:	81	91	01			78.6
Capital		34.4	24.4	24.4			
Recurring		7/yr					
Agriculture	Year:	81	91	01			53.9
Capital		10.6	7.5	7.5			
Recurring		6.5/yr					
Hydrologic Land Use	Year:	81	91	01			10.0
Capital		3.5	2.5	2.5			
Recurring		1/yr					
EROS Data Center	Year:	81	91	01			
Capital		13	9.2	9.2			120.9
Recurring		16/yr					
						TOTAL	442

and replacement of worn-out equipment. The yearly recurring cost is for the operation of all the above and for the operation of the Image Processing Facility.

The 1981 Agricultural capital cost is the cost of the initial construction of a LACIE computer facility for the United States Department of Agriculture and the subsequent capital costs are for the regular replacement of worn-out equipment. The recurring cost is for the operation of the facility.

The 1981 Hydrologic Land Use capital cost is the cost of the initial construction of facilities for the Corps of Engineers and the subsequent capital costs are for regular replacement of worn-out equipment. The recurring cost is for the operation of the facility.

The EDC capital cost is the cost of replacement of worn-out equipment at the physical facility at Sioux Falls. The recurring cost is for the operation of the facility.

3. AGRICULTURAL CROP INFORMATION

3.1 Introduction and Summary

LANDSAT Follow-on has been designed to monitor the worldwide production of food and feed crops. Total annual benefits to the United States from improved foreign crop production forecasts are estimated at $336 million to $581 million.

Within the United States, the Department of Agriculture (USDA) publishes crop production forecasts on the major field crops most months until the harvest is completed, and continues to publish production estimates through the end of the year. With regard to most other countries, however, data are not available until harvest time or even later, and in some cases are of dubious reliability. LANDSAT Follow-on offers a practical means of extending the U.S. preharvest forecasting system to other countries, yielding large benefits to the United States. The benefits result from making the information available freely, not from covert use of data. Further benefits may accrue if the U.S. crop reporting system can be improved in timeliness or accuracy through LANDSAT, but no improvement in the U.S. crop reporting system is assumed for purposes of computing the benefits reported here.

Two major classes of benefits arise from the improved world crop forecasts made possible by LANDSAT Follow-on, "distribution" and "production" benefits. Figure 3.1 illustrates how improved information leads to benefits in these two classes. The discussion in subsequent sections is also organized to follow this figure from left to right.

Distribution benefits result from distributing crops more efficiently in time and space. Temporal distribution is achieved by crop storage. Crops

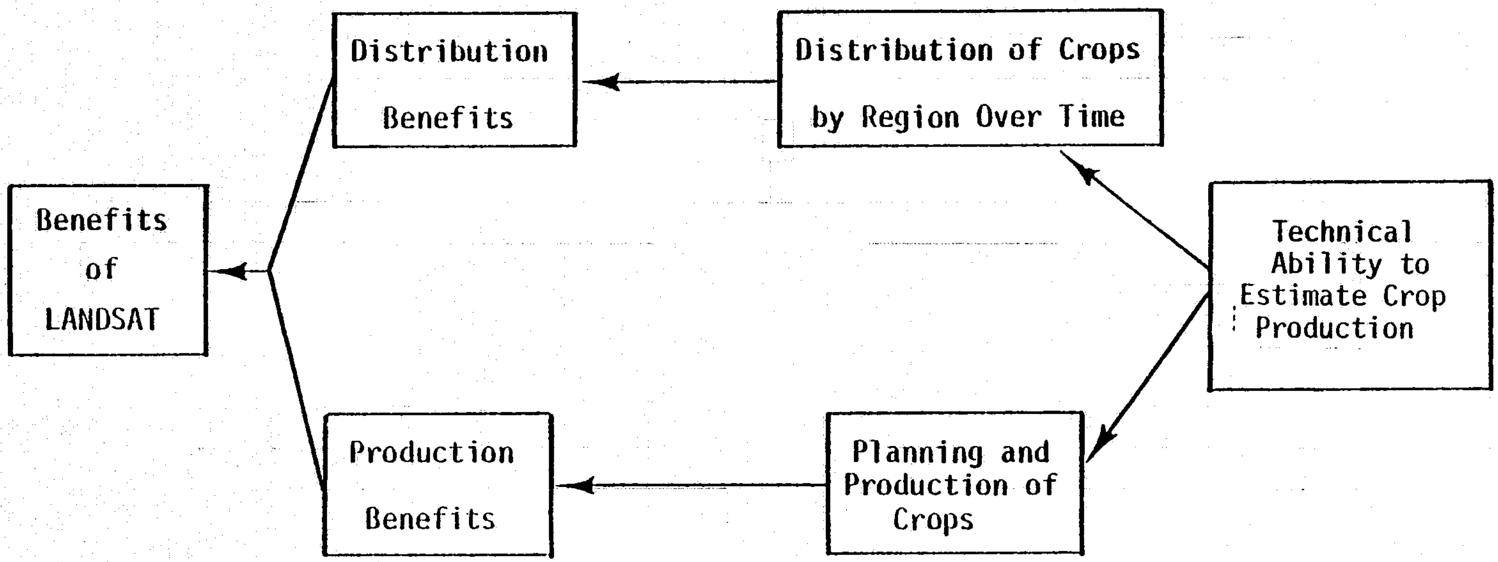

Figure 3.1 How Improved Information Contributes to Agricultural Crop Benefits

are stored or withdrawn in anticipation of future shortages or abundance. Storage is costly, however, in terms of inventory costs, physical costs of facilities and maintenance, and spoilage. Inventory costs are by far the most significant. Better information permits storage to be used more efficiently and the storage costs to be reduced, while the benefits of storage --steadier consumption and prices--can be increased. The other type of distribution benefit is one of place rather than time. Commodity trading redistributes the world's agricultural production; the better the information, the better the redistribution from areas of surplus to areas of need. Improved crop information permits the transportation and related costs to be reduced, while making prices and hence consumption more responsive to regional needs. The mechanism for realizing these gains is the world commodities futures market, not a hypothetical planning agency. Futures prices influence storage, withdrawal, and trade decisions, and operate in the direction of more even distribution in time and place when the accuracy of production forecasts is improved (Bradford-Kelejian 1974).

ECON has estimated the magnitude of the annual U.S. distribution benefits; none of the benefits to other nations are included. These benefits are shown under 'Distribution Benefits' in Table 3.1, and include $108 million for wheat alone, and $227 million for all 8 crops that were studied. These benefits are based on an improved estimate of foreign production where improved means the production estimate is less than 10 percent in error at harvest, 90 percent of the time.

Production benefits are the second major class of benefits derivable from improved information. These result from improved decisions that farmers can make with better knowledge of the predicted harvest, or in response to

Table 3.1 Annual U.S. Benefits from Improved World Crop Information[1]

Crop	Production Benefit	Distribution Benefit	Combined*
Wheat	162	108	224
Oats, Barley, Rye	0	4	4
Corn	48	87	97
Soybeans	7	10	11
Sugar	0	0	0
Potatoes	0	0	0
Total	174	227	336

*Production and Distribution benefits are not completely additive. The $224 million is based on an integrated evaluation of both effects.

the prices that reflect this better knowledge. At U.S. planting time, which may occur after crops are well under way elsewhere in the world, the farmer can make improved choices of which crops to plant and the acreage to devote to each. As the season progresses, the farmer can use improved information to determine the appropriate levels of investments to make in irrigation, fertilizer, and pesticides; and to determine whether to harvest the crop or plow it under. The planting decision is by far the most important, and is the one selected for modelling. Production information, of course, is only significant for crops that are important in world trade, and is only one element figuring in production decisions. The modelling work computes only the component of benefit derived from improved information and realized by U.S. producers or consumers.

The benefit appears in the form of more even production of crops. If forecasts are accurate, more production is encouraged when it is needed, less when it is not. Conversely, inaccurate forecasts tend to promote or discourage production at the wrong times, and crop production is less stable. Since the world's food needs are better served by stable production and stable prices, a benefit results from better forecasts (Heiss 1976).

It is important to not that the benefit is obtained if the information is published, whether or not every farmer reads the forecasts. The market mechanism adjusts spot and futures prices to reflect the forecasts, and it is the price level that operates to encourage improved decisions.

Table 3.1 shows the benefits anticipated for the LANDSAT Follow-on system. Production benefits and distribution benefits are shown separately and in combination. The effects are not completely additive, however, so that the 'combined' benefits are not always as great as the sum of the separate effects.

The table indicates that wheat and corn are the two crops accounting for nearly all the U.S. benefits from improved world crop information. The reasons are as follows:

1. In the case of oats, barley, and rye, and potatoes, little trade takes place

2. Soybeans are produced mainly in the United States, so that world crop data has little impact on U.S. decisions

3. Cane sugar is not grown in the United States, so that U.S. decisions have little impact.

The results shown in Table 3.1 reflect the baseline evaluation of the LANDSAT Follow-on by ECON, with conservative assumptions as to the technical and economic performance capabilities of the program. The numbers shown in Table 3.1 are certainly not exact since any economic estimate has some uncertainties associated with it. The range of benefits that might result from changes in the assumptions are shown in Table 3.2. Two sets of numbers are shown. The first column shows the baseline benefits and the second shows an upper bound. The baseline benefits result from conservative assumptions on economic and technical performances of the LANDSAT Follow-on system, and the uses of that information. For example, the Thematic Mapper will certainly meet the goals of the LACIE program in providing world crop information by region. However, the technical expectations are that the Thematic Mapper indeed can surpass those goals, leading then to larger benefits. Similarly, if the economic assumptions on the demand for wheat and other crops are changed to reflect risk aversion and nonlinear demand functions the benefits increase similarly. Thus, the upper bound column shows a reasonable, but more optimistic assessment of the benefits of the LANDSAT Follow-on program. The upper bound reflects a variety of factors that can make the application

Table 3.2 Likely and Potential U.S. Annual Benefits from Improved World Crop Information

Crop	Baseline*	Upper Bound**
Wheat	224	400
Other Small Grains	4	4
Corn	97	97+
Soybeans	11	80***
Sugar	0	---
Potatoes	0	---
Total	336	581

*Based on Table 3.1

**Based on Sensitivity Analyses

***Based on U.S. export effects in soybeans due to improved information on other crops worldwide.

of LANDSAT information in agriculture more valuable than assumed in the baseline assessment.

The results show the value of LANDSAT Follow-on information in agricultural crop markets to be about \$300 million with an upper bound of \$600 million a year by 1985.

3.2 Distribution of Benefits

The impact of benefits on various interest groups in the United States is an important concern. If the benefits of the LANDSAT Follow-on program were to accrue exclusively or foremost to a few private corporations, then the investment--however worthwhile--should be financed by those few who benefit from such programs. On the other side, if benefits are widespread, across a variety of groups, interests and regions, then programs considered for federal funding have met one important, necessary condition.

In the case of LANDSAT agricultural crop information, the main beneficiaries will be farmers and consumers. Considerable effort has gone into determining more precisely the exact share by farmers, as against consumers, but to date the results have not been conclusive.

The main, immediate effect of improved crop information will be more stable prices, while in the longer term production will increase at lower overall costs per unit of output. In the economic community there is some disagreement whether stable, nonsubsidized prices benefit farmers or consumers to a greater degree. ECON has the view that in closed economic systems such price stability as is created by improved information will mainly benefit consumers in the long run, although in the short run farmers are likely to be the main beneficiaries. The economic answers on the share in the overall U.S. benefits depends on many detailed assumptions and estimates, where a small change in parameters can lead to a substantial shift in the share claimed for farmers and consumers--without changing, however, the total estimated benefits accruing to the United States.

Table 3.3 reflects the qualitative judgment that the benefits from distributing crops better will accrue primarily to farmers, if current

Table 3.3 Long-Term Steady State Distribution of Benefits Within the United States		
Groups	Distribution Effects	Production Effects
Farmers	most	negligible
Traders	negligible	negligible
Consumers	some	most

assumptions in economic theory on the subject are accepted. In a competitive economic system, these benefits will undoubtedly also be shared by consumers over time. The benefits from production effects of improved crop information will go primarily to consumers.

Small traders and other middle men in the commodity markets between farmers and consumers cannot afford to collect more reliable worldwide crop information which a few large organizations and corporations can collect on their own. A truly worldwide, timely, public crop information system therefore can be expected to improve, marginally, the position of small farmers and traders relative to large trading and processing interests. Overall, in competitive economic systems the traders and processors will be about equally well off with or without improved crop information. There will exist a diminished need for hedging and speculative risk taking, which again is of some benefit to the economy and to consumers and farmers.

Other than this qualitative assessment, no further, more precise or quantitative statement can be made with assurance.

3.3 Estimation of Distribution and Production Benefits

In order to estimate the benefits of improved crop information systems, ECON has modeled distribution and production aspects of information in agriculture. These models were validated against the real world to the extent possible and used in determining the sensitivity of the benefits to alternative assumptions and capabilities.

3.3.1 Distribution Benefits Model

The Distribution Benefits model is concerned with measuring the benefits from the improved temporal and spatial distribution of food supply made possible by improved crop forecasts. The measure of benefit is the difference of the value of the crop as distributed with today's information, compared with the value that might be possible with improved information.

The model treats two kinds of distribution: that obtained by shipping commodities from one region to another, and that obtained by storing commodities for consumption in the future.

The role of information then is rather straightforward: International trade will be efficient only if one knows early enough about regional shortages; and similarly, commodities will be stored only if one knows early enough about particular future shortages of food.

The underlying logic of distribution benefits from improved global crop information is this:

1. Improved information from remote sensing leads to more accurate and timely crop forecasts. This improvement is measured by the reduction of the variance of crop forecast errors, month by month.

2. Improved crop forecasts lead to a better time pattern and level of inventory buildups and depletions, since crop forecasts are inputs to inventory holding decisions.

3. Different time patterns of inventory buildup and depletions will reduce the variability of the supply of commodities available for consumption.

4. This more even supply of commodities leads to gains to consumers and producers through price stabilization.

5. The exporters and importers share in the benefits in complex but calculable ways, determined by the workings of the free market.

Thus, improved information working through inventory decisions reduces the variance of food supplies, and thereby generates benefits.

The basic approach is that of modeling the distribution process as a dynamic control process (Andrews 1976). An overview of this basic model is given in Figure 3.2. Production of wheat in the United States and in the rest of the world is described by a stochastic production process which is considered fixed and exogenous to the control process. This is indicated by the oval block to the upper left. The three interrelated blocks constitute the distribution system which converts the worldwide production pattern into the worldwide consumption pattern. Also fixed and exogenous is the market demand model, which converts a given consumption pattern into economic value. This is shown on the middle right of Figure 3.3.

The distribution process, shown as a rectangular block, is simply the linear relation describing how exports, production and inventory adjustments affect the supply pattern. The system is subject to partial control through export decisions and inventory adjustments. The control is only partial since production has a random component. However, the application of the control is made in the light of estimates of supply provided by an information system. Simultaneously with the decisions on exports and inventory adjustments, the control block produces the consumption pattern as an output of the entire distribution system.

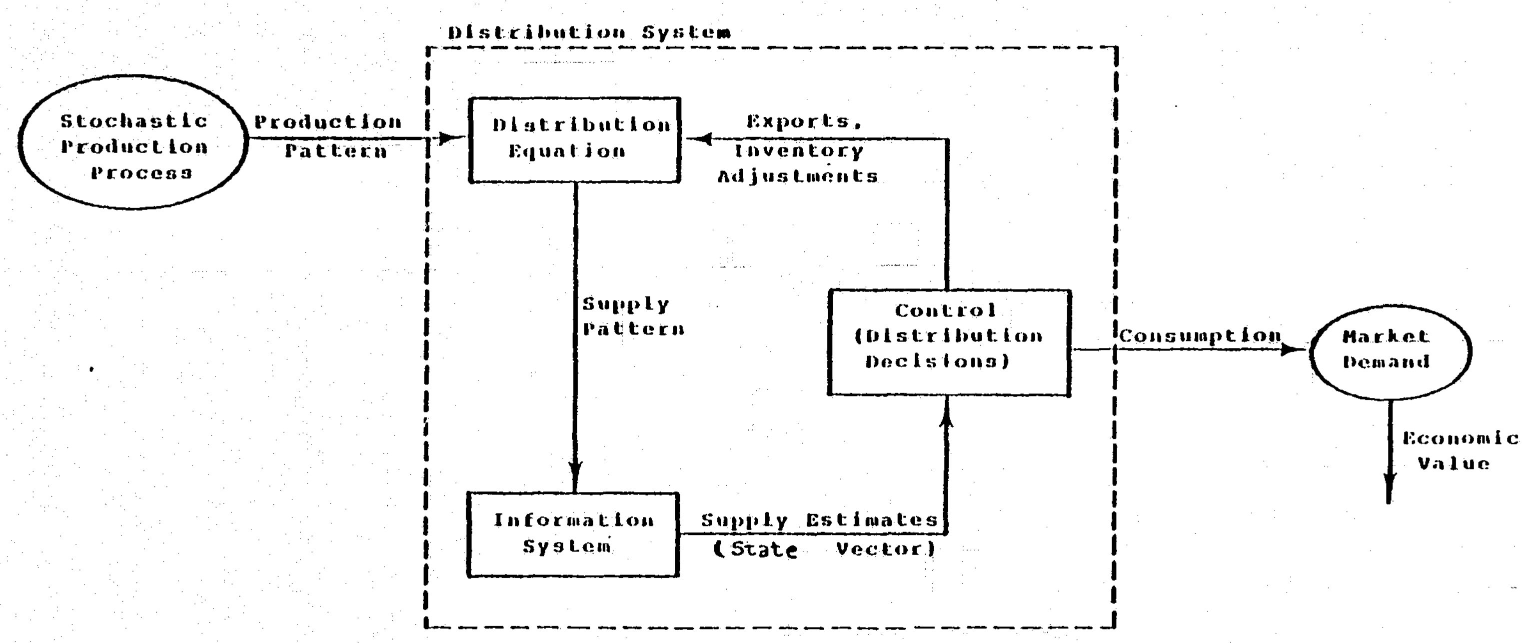

Figure 3.2 Overview of Feedback Control Model

The use of the model outlined above in determining the value of production information is straightforward. One simply observes how the optimum changes in response to selected changes in the information system. In a free market, nonoptimal distribution patterns cannot long survive because they would provide opportunities for arbitrage. In other words, the distribution decisions made by free market agents are such as to maximize the value to the economy.

3.3.2 Production Benefit Model

The underlying logic of production benefits from improved global crop information is as follows:

1. Improved crop forecasts will lead to more stable crop prices.
2. More stable crop prices make possible better planning decisions by farmers, storage decisions by inventory holders, and export-import decisions by traders.
3. Improvements in these decisions lead to an expansion of crop supplies available and reinforces price stabilization.
4. The reduced risk in the production and trade of crops, and the increased stability of supply represents benefits to the United States.

All these effects tend to occur simultaneously, as illustrated in Figure 3.3.

The production model contains four types of equations, which can be thought of as the four building blocks of the model. First, there are demand equations: for human consumption, for animal feed, seed exports and inventories. These equations are present both for the United States and for the Rest of World (R.O.W.). Second, the supply side is represented by equations for planted and harvested acres. Planting decisions are analyzed with respect to price wherever possible. The yield per acre is treated exogenously. Third, there are the market equations detailing spot and future prices in

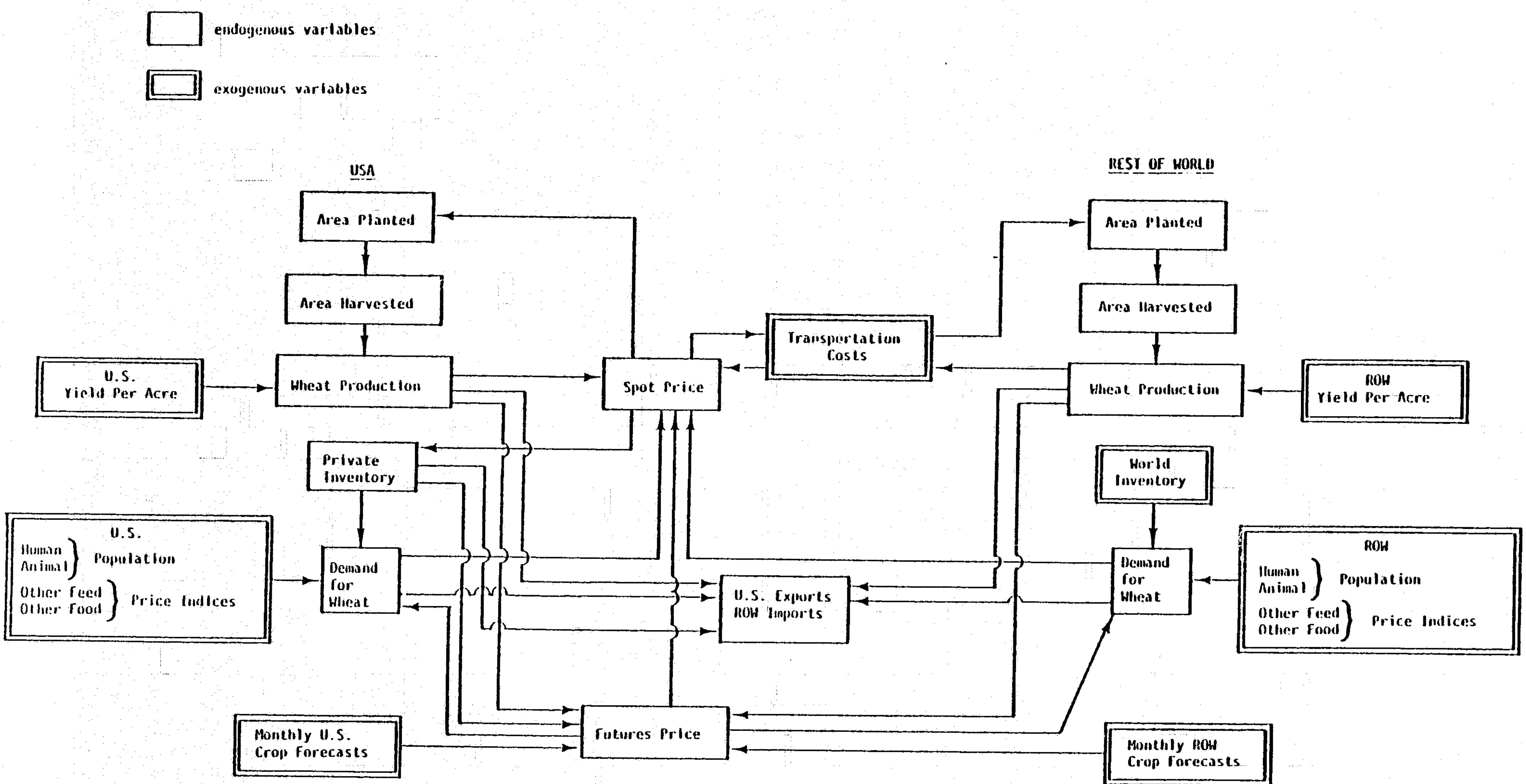

Figure 3.3 Flowchart of World Wheat "Production Benefits" Model

relation to supply forecasts and inventory levels. This block also contains equations representing hedging and speculation on the Chicago futures market, which is taken as the one world market for wheat futures. Fourth, the benefits of improved wheat forecasts are calculated in the final block, which compares prices and quantities under the historical regime of forecasting with prices and quantities under the simulated new regime.

We note that only planting decisions are modeled, as these are by far the most important production decisions. In the United States, planted acreage is used as a data input. In the rest of the world, harvested acreage is used as a stand-in for planted acreage, since in many cases the latter was not available.

Since the price and flow of commodities are conditioned by the availability of other substitutes (e.g., corn for wheat as animal feed), it is necessary to take into account the nonzero cross-elasticities of various crops with respect to the prices of their substitutes and complements. These factors are treated in the model as exogenous and appear in the various demand and supply equations.

The spatial equilibrium--the adjustment of prices, inventories, products and trade patterns--in the model arises from our aggregate treatment of the world as being divided into two regions: the United States and the Rest of World. This necessary simplification reduces "trade" to United States exports and R.O.W. imports.

Owing to the nature of this study, "time" also is an important dimension in the model. It is essential for a number of reasons. First, commodities can be carried fron one period to the next depending on the inventory holder's reaction to market anticipations. These anticipations can change from month to month and so can the inventory holders' positions. These changes, of course, influence benefits through price and consumption. Second, the benefits measured in this model, as in reality, depend heavily on the accuracy of market anticipations which, in turn, are a function of crop forecast accuracy. The forecasts play a central role in the model. They represent the best instrument we have for measuring the state of information on the future supply of commodities to the markets. By calibrating the model with historical forecasts and then replacing these by simulated forecasts which reflect the improvement in crop information resulting from the LANDSAT system, we have a tool for evaluating the economic effects of crop information in the world commodities market.

The heart of the production benefits model is the supply block, which describes the link of commodity prices to production decisions by farmers. The domestic production in any country is decomposed into harvested acreage A_t times yield Y_t.

The planted acreage of a crop in any period is related to the futures price of that crop, and the previous year's acreage.

Given econometric estimates of U.S. and rest-of-world demand and supply characteristics, estimates of the cost inventory holdings, and average values of commodity futures prices and crop forecasts, the model calculates the downward shift in the cost of supply as a function of forecast accuracies and timeliness.

The production benefits are derived from the effect of changed prices on changing total U.S. production. The changes in production (a net increase) is then related to changes (benefits) in domestic consumption, net storage and exports. These benefits are the result of increased production, lower costs of supplying commodities in combination with the increased consumption made possible by lower prices.

3.4 World Crop Information Today and With LANDSAT

While the measurement accuracies of a future global LANDSAT Follow-on system can be analyzed technically, one of the great difficulties today is to determine the current state of worldwide crop information. While most people would think that nothing is simpler than to estimate harvests, the fact is that today, no such revised final estimate exists for many countries. Furthermore, even where final estimates are available, they often vary widely from the forecasts made during the growing season.

In the worst cases, one finds that original planning numbers of some countries--say as part of a five-year plan--become precisely that country's crop forecast, which in turn becomes precisely the reported wheat harvest, with or without "overfulfillment" built in. It is difficult--on the face of such evidence--to get a true assessment of the accuracy of crop forecasts and measurements.

In the published forecasts of harvest by the world's largest grain producer, the USSR, there are apparently enormous errors and fluctuations. Witness the large surprise shortfalls in 1972 and again in 1975. In cases like this, the United States can benefit from more objective crop reporting, whatever the accuracy of the forecasts that may be employed within the USSR.

We note, however, that the quality of data for some areas of the world--notably the United States and Canada--is quite good (Gunnelson, Dobson and Pamperin 1972).

Estimates of LANDSAT's potential capability require understanding how remote sensing inputs fit into the total forecasting system.

The crop production forecasts are the result of a process of data collection, evaluation and integration which is illustrated in Figure 3.4, with results as illustrated in Tables 3.4 and 3.5. The errors in the final forecast are a composite of errors of sampling, measurement and inference. The LACIE goals of 90 percent accuracy, 90 percent of the time, were simulated for wheat production estimates with results as shown in Table 3.6. Using these simulated forecasts, one gets error rates which, in the case of foreign production, are a substantial improvement over the historical error rates; while in the case of the United States historical (USDA) accuracies seem to be better than the LACIE goals except in June and July. Of course, the historical accuracies cannot be perfectly known since final crop production estimates may still be subject to residual error. Thus, based on these statistics, we only claim significant improvement for the rest-of-the-world forecast accuracy. This assumption will result in conservative lower bounds for the improvement of accuracy of crop production forecasts. Any significant improvements of the yield component which develop will independently increase the overall accuracy.

The major sources of error in the crop estimates at harvest are measurement error and sampling error. In evaluating a new technology such as LANDSAT for obtaining crop measurement, a trade-off between the sampling errors and measurement errors arises. The existing technology gives estimates with higher measurement accuracy but much lower sampling fraction than the new technology. The total error is, of course, the only one that really matters. However, improvements may be achieved in either of the two dimensions of the

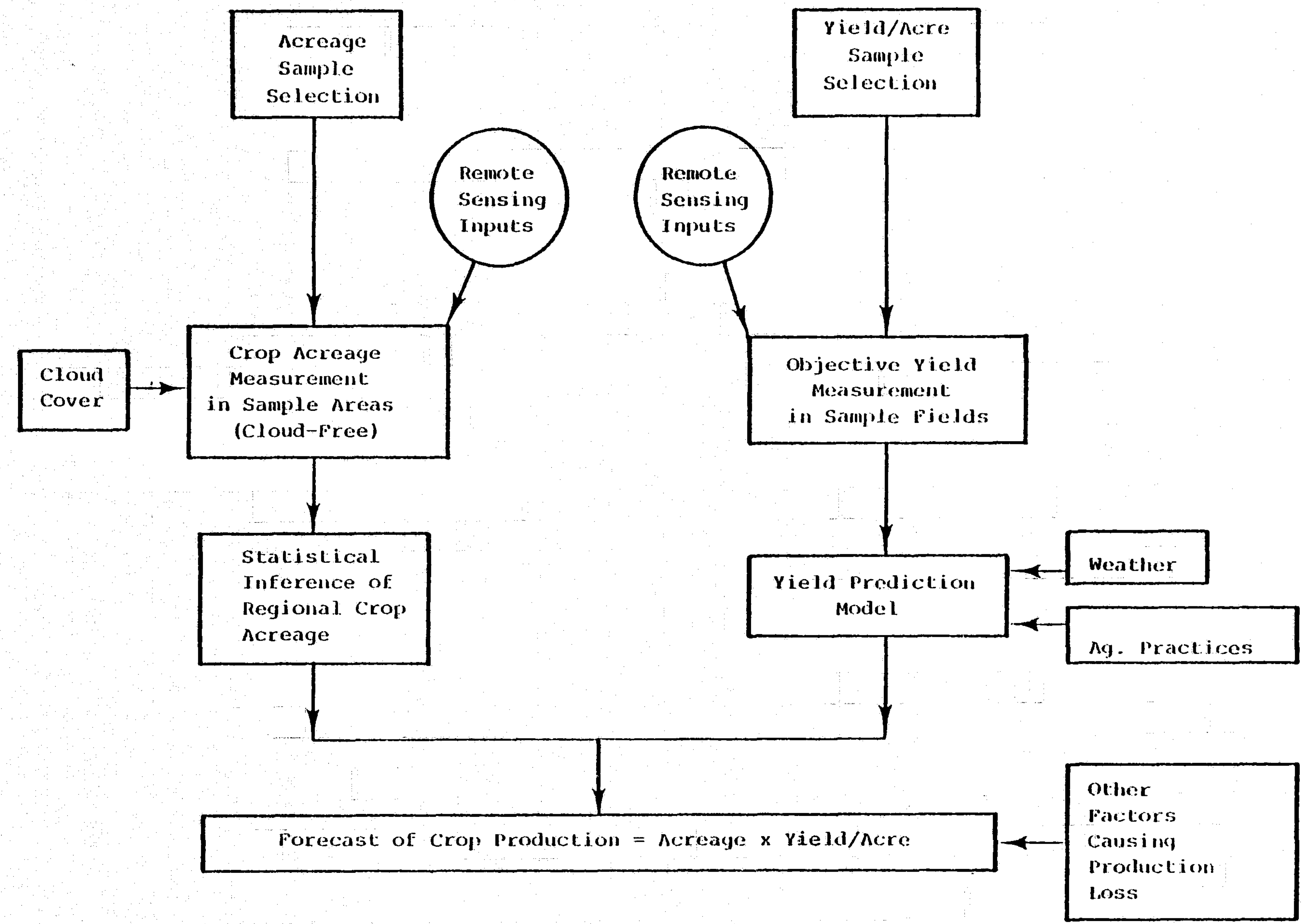

Figure 3.4 Illustrative Flowchart for Crop Forecasts

Table 3.4 Forecasts of the United States All Wheat Production in 1960-1974 and Final Estimates of Same (millions of metric tons)

YEAR	JUNE	JULY	AUG	SEPT	OCT	NOV
1960	33.0	36.7	37.1	37.2	37.2	37.2
1961	36.6	28.8	32.8	32.9	33.0	33.0
1962	28.8	28.6	28.9	29.8	29.8	29.8
1963	29.5	30.2	31.3	33.6	30.8	30.8
1964	33.0	34.7	35.0	35.1	35.0	35.0
1965	34.9	36.9	37.5	37.0	36.9	36.9
1966	33.6	33.8	35.0	35.3	35.3	35.3
1967	42.2	43.4	41.1	42.0	42.3	42.3
1968	33.5	43.2	43.7	43.5	43.5	43.5
1969	31.6	38.8	39.7	39.7	39.6	39.6
1970	29.3	36.7	36.9	37.0	37.0	37.0
1971	40.2	42.1	43.6	44.2	44.3	44.3
1972	42.1	42.2	42.0	42.4	42.4	42.4
1973	47.5	47.6	46.7	47.0	47.0	47.0
1974	55.9	52.4	51.6	48.8	48.5	48.5

YEAR	DEC	JAN	FEB	MAR	APR	FINAL
1960	37.1	37.1	37.1	37.1	37.1	36.9
1961	33.6	33.6	33.6	33.6	33.6	33.5
1962	29.7	29.7	29.7	29.7	29.7	29.7
1963	30.9	30.9	30.9	30.9	30.9	31.2
1964	35.1	35.1	35.1	35.1	35.1	34.9
1965	36.1	36.1	36.1	36.1	36.1	35.8
1966	35.7	35.7	35.7	35.7	35.7	35.5
1967	41.5	41.5	41.5	41.5	41.5	41.0
1968	42.7	42.7	42.7	42.7	42.7	42.4
1969	39.7	39.7	39.7	39.7	39.7	39.3
1970	37.5	37.5	37.5	37.5	37.5	36.8
1971	44.6	44.6	44.6	44.6	44.6	44.0
1972	42.1	42.1	42.1	42.1	42.1	42.1
1973	46.6	46.6	46.6	46.6	46.6	46.6
1974	48.8	48.8	48.8	48.8	48.8	48.8

Source: USDA *Crop Production Monthly*.

Interpolation by ECON.

Table 3.5 Forecasts of the Rest of the World All Wheat Production in 1960-1974 and Final Estimates of Same (millions of metric tons)

YEAR	JUNE	JULY	AUG	SEPT	OCT	NOV
1960	178.8	178.8	178.8	178.8	178.8	178.8
1961	183.8	183.2	185.0	174.9	172.7	172.7
1962	182.9	188.5	188.5	203.1	202.3	202.3
1963	192.2	189.6	192.6	200.9	201.6	199.6
1964	189.0	189.0	190.9	193.8	193.8	193.8
1965	195.9	199.3	201.2	209.1	208.5	209.1
1966	197.3	197.8	199.8	208.1	208.4	207.9
1967	207.1	212.4	212.4	212.1	215.1	231.1
1968	218.6	218.6	218.6	228.2	227.4	231.4
1969	242.8	242.8	242.8	243.2	243.4	243.1
1970	235.5	235.5	235.5	228.5	227.7	227.9
1971	250.8	250.8	250.8	259.3	260.3	260.3
1972	253.7	254.7	254.1	264.1	264.7	264.7
1973	272.4	275.3	272.6	272.6	269.8	269.8
1974	270.8	272.8	284.6	285.7	275.7	275.6

	DEC	JAN	FEB	MAR	APR	FINAL
1960	178.8	177.3	177.3	177.3	178.2	179.0
1961	172.7	172.7	172.7	172.7	174.9	175.0
1962	202.1	203.3	204.1	204.9	204.9	207.6
1963	200.6	202.8	205.9	205.9	205.9	179.5
1964	193.8	198.9	201.2	201.2	202.6	220.4
1965	207.2	205.2	204.8	193.9	191.9	195.1
1966	208.6	210.6	209.8	211.2	263.3	260.0
1967	231.7	228.2	228.1	228.1	228.2	219.5
1968	231.4	231.4	230.8	230.8	233.9	262.1
1969	246.0	246.0	246.2	245.2	245.2	240.2
1970	243.4	239.8	240.2	240.1	240.1	248.7
1971	259.1	259.1	257.5	257.5	257.5	269.8
1972	265.1	266.1	270.3	270.3	265.0	257.5
1973	288.9	288.9	289.1	289.1	289.1	296.2
1974	275.6	269.3	269.3	269.3	269.3	273.0

Source: U.K. <u>Grain Bulletin</u> and FAO <u>Production Yearbook</u>.

Interpolation and Extrapolation by ECON.

Table 3.6 Estimated Forecast Standard Deviation Percentage by Month Within Crop Year for 1960-1974 and Simulated LACIE Forecast Error Percentage

Time of Occurrence of Harvest	Month	U. S. A.* Historical	U. S. A.* LACIE	R. O. W. Historical	R. O. W. LACIE
Fall Sown Wheat in Northern Hemisphere**	May	5.93	5.63	8.24	10.81
	June	5.93	5.63	8.49	10.61
	July	4.38	5.46	8.30	9.59
Spring Sown Wheat in Northern Hemisphere	August	2.72	3.23	8.68	7.90
	September	1.91	2.27	8.33	6.39
	October	1.87	2.15	8.23	5.75
Fall Sown Wheat in Southern Hemisphere	November	1.87	2.15	8.29	5.65
	December	1.87	2.15	7.95	5.20
	January	1.87	2.15	7.61	4.81
	February	1.87	2.15	7.95	4.45
	March	1.87	2.15	7.64	4.40

Source: ECON calculations, assuming 6 percent standard error of the LACIE forecast at harvest in each country regardless of field size (90/90 goal).

*Since LACIE improvements for U.S.A. seem to be marginal based on assumed 90/90 performance goal, these changes were disregarded for purposes of this assessment.

**Except India, which has March-April usual time of harvest. The Indian crop was regarded as being already harvested in May.

error separately. The estimates of LANDSAT's capabilities for crop forecasting are based on ECON's interpretation of the "90/90" LACIE goal for wheat, assumed to be achieved also for the other crops reported.

3.5 Production, Consumption, and Trade in Seven Major Food Crops

For this study of worldwide agriculture, we selected for examination some basic grains, wheat, rye, oats, barley and corn; an important oilseed, soybeans; and sugar, both cane and beet. In addition to being among the most commonly grown and consumed foods, these commodities are widely traded on the world market. We also studied potatoes, which we limited to the United States only. While grown in much of the world, their low value-to-weight ratio and perishability make them of small importance in international trade.

Wheat

Wheat is the most important food grain in world trade. The other major food grain, rice, is generally consumed where it is grown. The U.S.S.R. is the world's largest wheat producer, accounting for up to thirty percent of the world production total, which for 1975-76 is estimated at 355.3 million metric tons. This has a value of $45.69 billion. The United States, with the December 1975 crop estimate of 58.07 million metric tons, is the second largest producer. The 1975-76 crop of all United States wheat is valued at $7.38 billion, with winter wheat being worth $5.78 billion and spring wheat $1.60 billion. The People's Republic of China, world's largest rice producer, is also growing a substantial amount of wheat.

The American wheat crop is comprised of two major crops of differing growing seasons, winter and spring. The winter crop is sown in the fall, lies dormant for the winter months, and is generally harvested in the late spring and summer. It is widely grown in the United States with the heaviest concentration found in the central and southern parts of the Great Plains. The five leading states (Kansas, Oklahoma, Nebraska, Texas, and Colorado) usually account for approximately sixty percent of the winter wheat crop. For 1975-76, winter wheat production is estimated at 44.94 million metric tons.

The remaining twenty-three percent of the total wheat crop, spring wheat (including durum), is grown almost exclusively in the northern plains states. Fully fifty percent of the spring wheat harvest is found in North Dakota with the remainder primarily concentrated in Montana and South Dakota. Spring wheat is estimated for 1975-76 at 13.13 million metric tons. The short growing season of three to five months, with planting in the late summer, is made possible by the high proportion of total rainfall that occurs in the summer months. The principal domestic uses for United States wheat production are cattle feed, various flours for human consumption, government inventories, and industrial brewing. Different types of wheat are used for different purposes. Hard wheat, usually spring, is used for bread flour due to its higher protein content. Soft winter wheat is used for cakes and crackers. Low grade wheat may be used for feed.

The export demand for United States wheat has been quite strong in the last few years as the U.S.S.R., People's Republic of China, and India have experienced poor crop weather.

United States wheat exports for 1975-76 are estimated at 36.74

million metric tons. Other large wheat exporters have traditionally been Canada and Australia, with Argentina recently entering the market. The major importers of United States wheat, in addition to the U.S.S.R., are Japan, the European community, People's Republic of China and Brazil. The United States has about forty-five percent of the world export market.

A five-year trade agreement between the U.S.S.R. and the United States was signed October 20, 1975. This allows the U.S.S.R. to buy a minimum of six million metric tons of wheat and corn each year, with the option to buy two million more.

Wheat futures are traded in the United States on several markets, reflecting their important place in trade. These are the Chicago Board of Trade, the Kansas City Board of Trade, the Minneapolis Grain Exchange, and the Mid-American Commodity Exchange in Chicago.

Corn

Corn is of major importance for feed, food and industrial uses. The varieties number in the thousands, but there are seven major types, each grown in a particular area of the world. Some countries grow more than one type. The United States, which produces over fifty percent of the world's corn, grows sweet corn, popcorn and corn for meal and flour, as well as for feed. Most United States corn is of the hybrid type, which has higher yields than the older, open-pollinated types. United States corn production in the 1975-76 season has been estimated at 146 million metric tons, with a value of $15.09 billion. Exports for the 1974-75 period were 28.6 million metric tons. Major importers of United States corn include Japan, Italy, the Netherlands, West Germany, Spain, and the United Kingdom.

Corn can be grown successfully in the humid tropics and subtropics, and in the warmer parts of the mid-latitude climates. In colder areas of the world, such as Canada and the U.S.S.R., it may be grown for green feed rather than grain. Besides the United States, major growers include Brazil, South Africa, Mexico and Yugoslavia. World corn production estimated at 3.15 million metric tons in 1975-76, is valued at $32.625 billion.

Corn has a wide variety of uses. Foremost is its use as a feed grain, in which it is considered superior to most others for poultry, cattle and hog feed. The stalks and cobs are also important as stock feed. Dry mills produce grits, meal and flour. Wet mills divide the corn into starch, gluten and oil, which are in turn used by industry for a variety of products, including sugar, syrup, soap and alcohol.

Corn futures are traded at the Chicago Board of Trade.

<u>Soybeans</u>

Soybeans are of increasing importance, both as food for humans and for animal feed. The United States is the world's largest grower, supplying over eighty percent of the world's soybean exports. Soybean production has been increasing rapidly in the United States and has more than doubled since 1960. The 1975-76 crop valued at $6.778 billions, is estimated at forty million metric tons. Exports from the United States totaled 13.6 million metric tons in the same period. The primary soybean producers are the north central states, although the south central and south atlantic states have also responded to the recent explosion in soybean demand. Illinois and Iowa usually account for about thirty-four percent of the total United States production.

The domestic demand for processed soybeans is divided into the meal and oil market. The soybean meal, which is over sixty percent of the combined processed product value, is used for livestock and poultry feed where it competes with cottonseed, sunflower, peanut and fish meals, and tankage, a slaughterhouse by-product. Almost all United States soybean oil is used in food products, such as margarine and shortening, where it competes with cottonseed oil and lard, both by-products of other industries. Palm oil has recently become a competitor of soybean oil in the United States. Nearly all meal goes into the production of high protein feeds.

Brazil is the second largest grower, having recently dislodged China from that position. China, the third major grower, is now importing some soybeans to meet its own needs. Many countries import soybeans, soybean meal and oil. This includes Japan, the largest importer; Spain, Denmark, the Netherlands, and West Germany. The world soybean crop for 1975-76, estimated at 61.3 million metric tons, is valued at $10.355 billion.

Soybean futures are actively traded at the Chicago Board of Trade.

<u>Sugar</u>

Sugar is actually the refined product of two separate crops, sugar cane and sugar beets. Few countries grow both cane and beets—the United States is one exception—as the climatic conditions needed for each crop are very different. Sugar cane is grown mainly within thirty degrees of the equator in the more humid areas of Asia, Africa, America and the Pacific Islands. Sugar beets are widely grown in the northern latitudes as part of crop rotation plans, since they will grow in many soils and elevations. Both the dried beet tops and the by-products of beet processing, pulp and molasses, are mixed with grains for animal feeds.

More than one hundred countries grow sugar cane or beets. Over two-thirds of all sugar is consumed where it is produced. Large exporters include Cuba, Australia, Brazil and the Philippines. The United States is the largest importer, followed by Great Britain, Japan, U.S.S.R. and Canada. Sugar is traded worldwide under various agreements and on an open market basis. Such traded sugar is centrifugal raw sugar. Other noncentrifugal sugars are consumed where produced, as they vary in quality and do not keep well.

Due to larger plantings, the world sugar crop for 1975-76 was of record size. It was estimated at 90.3 million short tons, having a total value of $36.769 billion (raw value). The United States, in the same period, produced beet and cane sugar totaling 5.4 million short tons (raw value) worth $2.172 billion. Beet farmers in the United States grow their crop on contract with the large refiners, and know in advance what price they will be paid.

In November 1975, the President signed a bill which designated sugar as one of a group of duty-free commodities, within certain limits. This Trade Act Authority will expire in January 1985.

Sugar futures are traded in the United States on the New York

Coffee and Sugar Exchange. Two contracts are used, a more active No. 11 "world sugar," and a No. 12 contract for "domestic sugar." There are also active sugar futures markets in London, for raw sugar, and in Paris, for refined sugar.

Refined sugar is interchangeable with dextrose, corn syrup and corn sugar for some purposes. Other substitutes are honey, maple syrup and sugar, and fruit sugars. Non-food uses of sugar include paints and varnishes, plastics, agricultural chemicals, detergents, fibers, films, solvents, explosives and adhesives.

Small Grains

Rye, oats and barley are important feed and food grains. Barley, along with corn, is one of the most important feed grains. Total world production of small grains for the 1975-76 crop year is estimated at 226 million metric tons, having a value of $29.447 billion.

In the United States, small grains are grown mostly in the northern plains and Great Lakes states. Rye has a long growing season of eleven months, and is used as a cover crop, pasture and green manure. Only about thirty-five percent of the acres planted are actually harvested for grain. Both barley and oats are mostly planted in the early spring and harvested in late summer and early fall. Most oats and barley in the United States are used as feed, with the primary use of harvested rye being for bread flour. Based on December 1975 estimates, the United States small grains crop, at 23 million metric tons, had a value of $2.281 billion.

Barley

Barley has been widely grown as a staple food, although it has declined in importance, being replaced by wheat, rye and rice. It is chiefly used today as livestock feed, and for malting, brewing and distilling. Heavy yielding varieties have recently been introduced; some of these are specialized for malt production. As a feed grain for pigs and cattle, it competes with corn, low-grade wheat, oats, sorghum, rye and beans. Demand for barley as feed is affected by supplies and prices of these competitors.

Most barley is grown in Europe which, including the U.S.S.R., accounts for about sixty percent of the world total. India, Turkey, Australia and the northern African countries also have sizeable barley crops. North America grows less than twenty percent of the world crop. In the United States, barley is an important crop in several north central and northwestern states, but constitutes only a small part of the overall grain corp. In 1975-76 production was estimated at 8.3 million metric tons, valued at $1.162 billion. Exports account for about 1.1 million metric tons in the same period. World barley production for the crop year of 1975-76 was estimated at 14.9 million metric tons. This had a value of $20.813 billion.

Oats

Oats and rye are grown mainly in the cooler areas of the world. Unlike rye, however, oats are not winter hardy and are usually planted in the spring. Oats are widely grown in Great Britain, northern Europe, the Scandianvian countries and North America. The U.S.S.R. is the world's largest producer, followed by the United States, Canada, West Germany, and Poland.

In Canada, oats are the most important feed grain, competing with barley. Oats are number two in the United States, competing with corn. United States oats production in 1975-76 totalled an estimated 9.8 million metric tons, with a value of $1.119 billion out of a world crop estimated at 51.3 million metric tons, valued at $5.832 billion. For the same crop year, 1975-76, United States exports are estimated at 362,875 metric tons.

Only a very small percentage of oats, particularly in the United States, is used for human food. Industry uses some in plastics, rubber and lubricating oil. In the United States, about twenty-five percent of the oats planted is used for silage or forage rather than grain. Scientific advances have nearly doubled yields per acre since World War II. The highest yields per acre, however, occur in smaller countries, since the U.S.S.R. and the United States sacrifice higher yields to the use of mechanized farming methods.

World trade in oats is small due to its bulkiness and weight, which results in high transportation costs. On the market, the price of oats is greatly influenced by the price of corn, since they are fairly interchangeable for feed purposes.

Rye

Rye, of minor importance in the United States, is used in many parts of the world as a bread grain. It is the only other grain besides wheat which, by itself, can be baked into a loaf. Wheat is taking the place of rye as a bread grain in more affluent areas of the world. Most of the world's rye is grown in Europe, with the U.S.S.R. being the number one grower. Poland and West Germany are the second and third largest growers. These three together account for about eighty percent of the world production of rye. World production of rye for the year 1975-76 is estimated at 26.1 million metric tons, to which the United States contributed about 472,000 metric tons. Exports from the United States accounted for an estimated 76,200 metric tons. The value of the world crop is $2.802 billion, the United States crop being worth $50.728 million of that total.

Rye is useful as a feed, particularly for hogs, but it is considered inferior to barley, corn and oats for that purpose. In Europe, it is fed to bacon hogs, dairy cows, and baby beef steers. Rye produces a long straw which is used in the manufacture of paper and cardboard. A small but increasing quantity of rye is used for distilling.

The largest futures market in small grains is the Winnepeg (Canada) Commodity Exchange, where rye, oats and barley are all traded. Oats are also traded at the Chicago Board of Trade.

Potatoes

Potatoes in the United States are grown in every state. Maine and the Pacific Northwest are the prime growing areas. Maine's production is important to the overall domestic supply; economic factors of Maine potatoes affect other areas of the country. Potatoes are classified as winter, spring, summer or fall, with about two-thirds of the crop being fall potatoes. Climate is important to production, with best growth taking place in cool, humid areas having good rainfall.

Potatoes are grown primarily for domestic consumption as a food crop. There has been an expansion of processed potatoes in the last fifteen years of over five hundred percent. Frozen and dehydrated potatoes account for over fifty percent of United States production. Poorer quality potatoes are processed for starch. Some potatoes are used for livestock feed, seed and export. Exports are minor, however, as there is little foreign trade in potatoes involving the United States. This is due both to transportation costs, and the possibility of spreading pests and diseases through shipments of fresh potatoes. There is some export trade among European countries, particularly in the Common Market countries.

4. PETROLEUM AND MINERAL EXPLORATION

4.1 Introduction and Summary

LANDSAT is already a tool for petroleum and mineral exploration as evidenced by the testimony of exploration companies. The added spectral bands and increased resolution of the thematic mapper promise to make it far more effective.

Benefits from this application of LANDSAT may be divided into two categories:

<u>Cost savings</u> are achieved in the exploration for both petroleum and minerals, because LANDSAT is useful in screening prospects, laying out geophysical surveys more efficiently, and achieving exploration goals at lower cost. Total savings to United States companies are estimated to be not less than $42 million annually, based only on efficiencies demonstrated from early LANDSAT experience without the thematic mapper. With the thematic mapper larger benefits are anticipated, owing to the greater efficiency of screening prospects that should result from additional spectral bands and greater spatial resolution.

<u>Increased values</u> are obtained from earlier recognition of good prospects. A prospect has a market value that takes into account remaining exploration, development and recovery costs; the probable yield of the ore bed or petroleum field, and the perceived risks at each stage. The benefit derives from capturing this market value at an earlier date. Although there is good evidence that LANDSAT can speed up prospect recognition, some further study is required to permit estimating LANDSAT's quantitative effect, and to assess the market values of the resulting prospects.

A case can also be made that LANDSAT should speed the discovery of petroleum in countries not currently holding proven reserves. This should be of major benefit to oil importing nations, as extra producers will tend to reduce the price level at which OPEC can effectively control production levels. The magnitude of this effect is very difficult to estimate, although it is potentially of major significance.

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In summary, estimated benefits of LANDSAT to petroleum and mineral exploration are $42 million annually, with indications that this may well be a major underestimation.

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A few final comments are merited. First, cost savings resulting from improved efficiencies tend to be <u>reinvested</u> in further exploratory work, since the "cost per find" is reduced while the market value is not. The "cost-saving" measure, therefore, is a minimum valuation procedure. Second, many LANDSAT images of the same area may be used in screening, since subtle differences in lighting, soil moisture and vegetative color provide valuable clues. Several years of thematic mapper imagery will be needed to provide a reasonably complete set of data for this application; a single, complete set of images would have more limited usefulness. Furthermore, an iterative process of cross-checking between imagery and field investigations is required, so that the benefits are likely to be realized over a period of many years.

4.2 Cost-Savings Effects

In petroleum and minerals exploration it is rare for any one tool to provide definite evidence of a new reserve. Instead, the process is one of developing and then screening prospects by various criteria, reserving the larger investments in test drilling for the best prospects. See Figure 4.1 for illustration.

The evidence that LANDSAT can provide is of fracture patterns, suggestive of mineralization; domal outlines and definitions of other structures suggesting locations in which petroleum or minerals may be concentrated, and color differences in rock or vegetation, which may represent alterations indicative of minerals or hydrocarbons. In some cases non-LANDSAT techniques will have suggested prospects that LANDSAT data can be used to screen or focus, while in other cases the LANDSAT data may be used to suggest prospects to be evaluated by other techniques. The two processes are really intertwined, although for convenience we may regard the former as augmenting the efficiency of exploration geology and geophysics, and the latter as creating prospects with a certain market value. This market value would not be created as soon, if at all, in the absence of LANDSAT.

LANDSAT's principal efficiency benefits are to be found in the mapping, reconnaissance and targeting portion of what are usually termed "geology and geophysical exploration" activities.

Unfortunately, no reliable estimates are available on what U.S. petroleum and mineral exploration companies spend on the mapping, targeting and reconnaissance function. N. Short's analysis suggests that a good estimate would be 20 percent of geology and geophysical costs in the case of petroleum exploration and one-third in the case of mineral exploration.

Geology and geophysical costs are also somewhat uncertain. As shown in Table 4.1, U.S. petroleum companies appear to spend some $800 million on this function on a worldwide basis. U.S. mineral companies, as shown in Table 4.2, spend an estimated $80-85 million in the United States alone, with probably

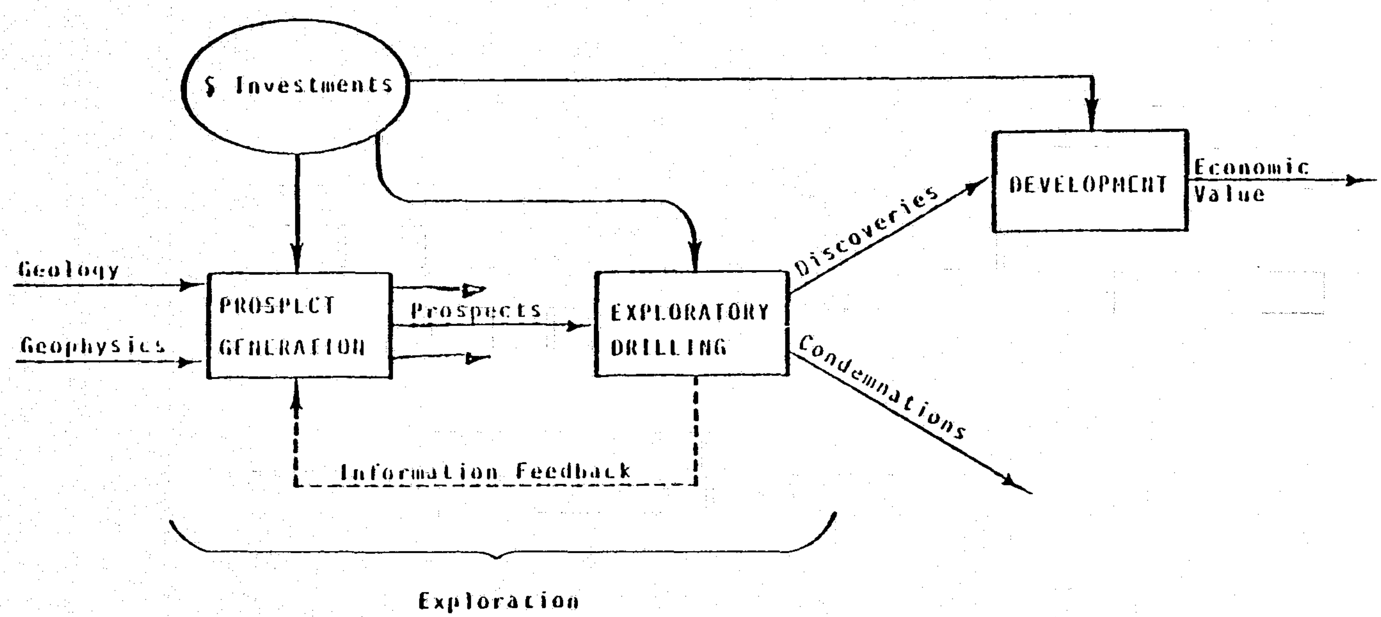

Figure 4.1 The Exploration and Development Process

Table 4.1 Exploration and Geology-Geophysics Expenditures by U.S. Petroleum Industry

Exploration	G&G[1]	Period/Place	Source
$3.4B	372M	1972-U.S. Domestic	World Oil, February 15, 1974, p. 86
$5.2B	925M	1974-U.S. Domestic	Chase Econometrics, Capital Investments of the World Petroleum Industry (1974)
	349M	1970-U.S. Domestic	Joint Association Survey
	640M	1974-U.S. Domestic	Joint Association Survey

[1]Only an estimated 60 percent of United States and world G&G costs are conducted on-shore, and relevant to LANDSAT.

No definite data has been found on the worldwide expenditures of U.S.-based petroleum companies, but we estimate that the non-U.S. expenditures are about 75 percent of the United States expenditures.

Conclusion: World on-shore G&G expenditures by U.S.-based companies are approximately $800 million.

Table 4.2 Exploration and Geology-Geophysics Expenditures by U.S. Minerals Industry

Exploration	G&G	Period/Place	Source
$200M	25% of metals exploration costs	1969-U.S. Domestic (Metals only)	National Academy of Sciences 1969
$400-1000M[1]			Batelle: Final Report on R&D in Mining, Minerals and Metallurgy (1972)
$245M-Metals $172M-Nonmetals		1975-U.S. Domestic	N. Short (1976) analysis based on reports of 5 leading companies
	55% of metals exploration 10% of nonmetals exploration		N. Short analysis based on private conversations

[1]Short considers the Batelle estimate to be based on a significant overestimate of the number of companies active in exploration.

Conclusion: G&G expenditures in the United States are approximately $80-85 million annually.

twice as much spent outside the United States. The mapping, targeting and reconnaissance costs would therefore be about $160 million and $80 million for the petroleum and minerals cases, respectively.

LANDSAT's potential impact on these costs is also difficult to assess. Table 4.3 shows the various estimates that have been made of LANDSAT's impact on petroleum and mineral mapping, targeting and reconnaissance costs. From these we infer a conservative 22 1/2 percent cost savings or $26 million in the petroleum case; and a conservative 15 percent cost savings or $16 million in the mineral case. The total annual savings would be about $42 million. The thematic mapper, furthermore, should provide greater cost savings through the improved screening potential of the extra spectral bands and greater spatial resolution. Realistically, companies will usually reinvest such cost savings in their exploration program, so much of the cost-savings benefit from LANDSAT will be reflected in more effective programs.

Further efficiency gains might be expected if it can be shown that LANDSAT permits reduction in the amount of geophysical survey work or the number of drill holes required without reduction in effectiveness. Although this is reasonable to expect, no direct proof is yet available.

4.3 Increased Value of Prospects

There is substantial evidence that LANDSAT can enrich the numbers of petroleum and mineral prospects to be screened, as well as providing greater efficiencies in screening the prospects generated from other evidence. These prospects have some "market value", and hence are properly regarded as benefits. If the prospect is one that would have been discovered later, by other means, the benefit lies in the earlier capture of the market value.

Table 4.3 LANDSAT Cost-Savings Estimates in Petroleum and Mineral Exploration (Relative to Mapping, Targeting and Reconnaissance Costs)

Estimate	Source
15% efficiency increase	N. Sharon, National Lead Industries
33%[1,2] savings in regional geological mapping	R. Houston, University of Wyoming
90%[1,2] savings in regional mapping and reconnaissance	M. Liggett, Argus Exploration
90%[1,2] savings in small scale structural analysis	D. Saunders, Texas Instruments
10-50% savings on early phases of exploration	Other, private sources as quoted in N. Short's analysis

[1] Mapping, Targeting and Reconnaissance is not limited to regional mapping or structural analysis, so the proportional savings in MT&R would likely be less than these values.

[2] No specific allowance is made for the loss of detail relative to alternative methods, some of which might require compensation.

Conclusion (after N. Short): A 15 percent savings of MT&R costs in petroleum exploration and 22½ percent in mineral exploration should be achievable by using LANDSAT imagery.

The prospects generated by LANDSAT are of several major kinds, as reported by Dr. Short (1976) in his analysis:

- Fracture patterns Abdel-Gawad, conducting a pilot study in east-central Nevada, has shown that known mines tend to lie at or near fracture intersections, and that other fracture intersections have unusually great evidence of mineralization.
- Color anomalies These may be indicative of alteration by significant trace minerals, escaping hydrocarbons or other significant geochemical events. Sar Cheshnich in Iran, Geotz and Brockman in Bolivia, and Schmidt in Pakistan have demonstrated that band-ratio anomalies can be used to find alteration zones, many of which were shown on subsequent ground investigation to be good mineral prospects.
- Structural anomalies These can be revealed by preferential stream and lake alignment, as investigated by Pickering in Georgia and several investigators in Alaska. Some of these are under active test for petroleum and natural gas at this time, although no conclusive results are yet known.
- Botanical anomalies These sometimes indicate trace elements in the soil, and can be detected with enhanced, and usually repetitive, LANDSAT imagery. National Lead has publically attributed a major find of zinc to the tonal differences in vegetation caused by zinc and cadmium in the surface soil. Similar patterns have revealed four additional commercial deposits outside the original zone of exploration.

The prospects generated by LANDSAT require checking out by other methods including surface investigation, geophysical techniques and test drilling before a "find" can be declared or a prospect rejected. One cannot, therefore, regard LANDSAT's value in this application as either the full value of reported "finds" or limited to only the "finds" that have been verified.

Prospects in themselves have a definite economic value, however. In the oil industry, for example, many companies and individuals capitalize on this value directly by trading or selling their ideas, rather than investing in exploratory drilling and later development. Generally, both buyer and seller try to evaluate the worth of a prospect by estimating the present value of the future profits and losses, given the probabilities of various exploration and production outcomes. This can be done with some precision when the prospect has been discovered by more or less standard techniques, and lies in a fairly well-explored area.

It is much more difficult to evaluate the worth of a LANDSAT-discovered prospect. First, there is much secrecy, because companies--quite properly--regard data on prospect quality and market value as valuable in itself. Second, LANDSAT is so new that too few LANDSAT-generated prospects have been pursued to provide a meaningful data base on probabilities.

The best method of arriving at realistic estimates of prospect values is to model a typical evaluation process, and attempt to determine the downstream probability distributions. This requires statistical evaluation of the investigations cited above, enhanced by informed opinions. Such modeling needs to consider the progressive depletion of various areas of the globe in ore-bodies or petroleum beds showing LANDSAT-detectable manifestations, along with the costs of following up the prospects.

Figure 4.2 provides an illustration of how prospect quality declines over time. Only a fixed number of prospects are available to be found and it is the nature of the economic process that the best prospects will tend to be found first. What better information such as from LANDSAT can do, is to accelerate the process, so that some of the good prospects that would otherwise be available years later, might be added to the prospect inventory now.

Work of this kind is now in progress, but results are not yet available. At this time, we do not attribute specific values to the LANDSAT-generated prospects, or the economic worth of obtaining these prospects sooner than would be the case without LANDSAT. Nevertheless, given the current high expenditures of oil and mineral companies aimed at finding prospects, the values must be very large.

4.4 Price Effects--Imported Oil

LANDSAT is particularly valuable as an aid to exploration in relatively remote regions, where extensive surface and seismic exploration may not have already occurred. It may very well serve to expedite the discovery of petroleum reserves in countries where petroleum is not now known to occur. Small countries, eager for petroleum earnings, can exert great pressure on OPEC in that even a small reduction below the OPEC price would enable them to sell all the petroleum they wished. OPEC needs to accommodate their production desires almost fully in order to maintain control of the market. As more countries become potential producers, the net effect is likely to be a restriction on the degree of control that OPEC can exert on world production, and hence, prices. It is impossible to quantify the degree of this outcome or the likelihood of its occurrence--but even an uncertain likelihood of a

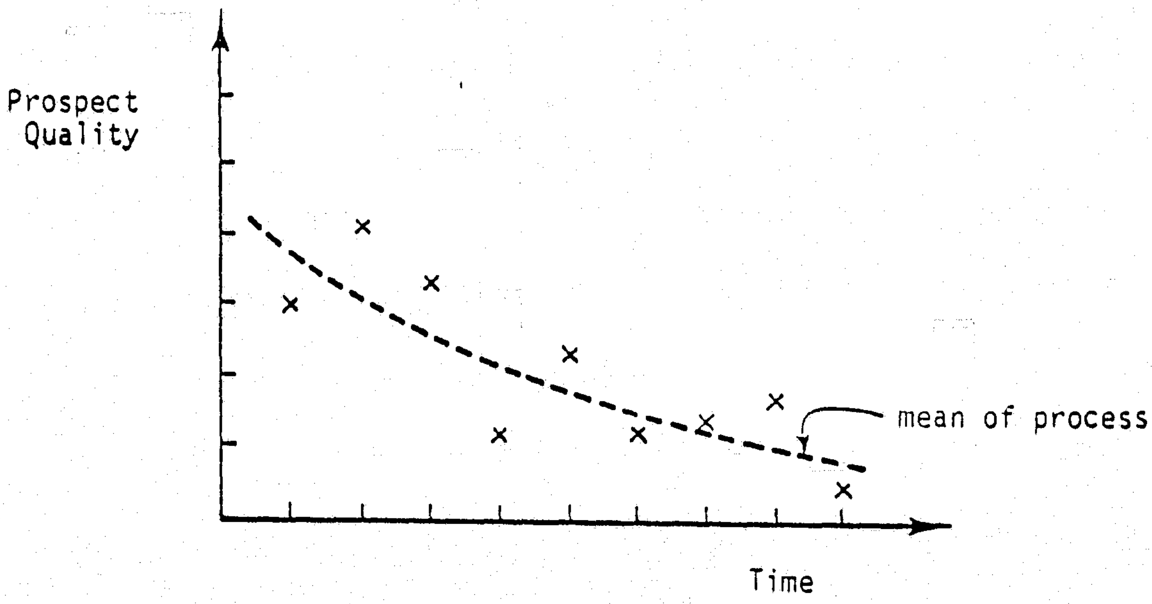

Figure 4.2 Example of Random Decline of Prospect Quality Over Time

very large benefit should have some recognition in LANDSAT's favor for this application.

Counting only the efficiency benefits in mapping, targeting and reconnaissance that were discussed in Section 4.2, a total benefit of $42 million can be attributed to LANDSAT's application to oil and mineral exploration. There are good indications, however, that the values of accelerating the discovery of prospects, or expediting the entry of new countries into the world petroleum market, may add tremendously to LANDSAT's value in oil and mineral exploration.

5. HYDROLOGIC LAND USE

5.1 Introduction and Summary

The amount of money spent on water resource systems planning and management is very large. The total federal expenditure for water resource development programs in FY 77 is estimated to be $2.9 billion (Office of Management and Budget, 1976b). The expenditures of local governments on urban water resources problems is $12 billion per year (Office of Water Resources Research, 1971). In metropolitan areas these expenditures constitute 20 percent of the total public expenditures (Koelzer, 1972).

Many of the planning and preliminary design activities on the part of federal, state, and local agencies require land use or surface cover maps. These show the present varied activities occurring within watersheds and provide input data for watershed models which produce estimates of snow runoff volumes, minimum and peak flows, and the assurable flow and minimum flow. Storm runoff volumes and peak flow rates are needed to plan municipal water systems, storm sewers, the size of reservoirs and dams, and flood control structures. Although it is often assumed that most agencies have access to current landuse maps, this is often not the case. In addition, even when maps are available they may not provide the type of information needed for watershed runoff prediction models or engineering design studies. The Landsat satellites can provide maps and numerical data that are timely and accurate, particularly for watersheds larger than 10-20 kilometers. In addition the processing of Landsat data can be done in a fraction of the time required by conventional systems.

The remainder of this chapter will document the estimated net savings in the $15 billion spent annually for water resource systems planning efforts. The end result is that the annual minimum of $33 to $35 million of data preparation expenses could be impacted and a net savings of approximately $22 to $23 million per year achieved.

The benefits of using Landsat to provide planning inputs arise not only from savings in imagery costs, but also from the ability to automate tasks that otherwise would be performed by hand. These tasks include developing classification systems, measuring areas with a planimeter, and coding information into a form suitable for input into watershed models or other computer programs. Since Landsat data has uniform scale and spectral characteristics, automated systems for data analysis and interpretation can readily be employed. The greatest cost savings are anticipated in applications lending themselves to such automation. Automation can also speed the planning of projects and permit them to be completed much sooner. If funds saved in planning were reinvested in the same programs, as often will be the case, a compounding of benefits could be expected.

It is important to note that water resource planning is an activity that will very likely increase during coming years due to legislation such as the Federal Water Pollution Control Act of 1972. Not only does continuing economic development pose new and different needs for water sources, water treatment, and flood control, but the changes in landuse alter the runoff and pollution parameters needed in the planning models.

Substantial changes in landuse and surface cover are occurring in the United States which require an ability to monitor and translate them into information in order to plan and design water resource systems. Many sources document the scope of the coverage required. The Commission on Population Growth and the American Future (1972), Statistical Abstract of the United States, U.S. Bureau of the Census, (1972), Resources and the American Future by Landsberg et al. (1972), the 1972 OBERS Projections (Bureau of Economic Analyses/USDC and Economic Research Service/USDA, 1972), and an article by W. Langbein in Pregel et al. authoritatively show that urban land will increase from 19,000,000 to 32,000,000 acres by the year 2000. This urban land will encompass nearly 150 metropolitan areas where 70 to 75 percent of the nation's people will live. In addition there are 35,000,000 acres of irrigated land, in the western United States primarily, that should be surveyed periodically to estimate water requirements. This acreage is expected to increase to 40,000,000 acres by 2000. Other major water resource areas that need to be surveyed periodically are floodplains and wetlands because they are important ecological and recreation areas and regions where substantial damage may occur if industrial development occurs. We believe, therefore, that the annual savings of $22 to $23 million are conservative.

5.2 Derivation of Benefits

The first task was to identify the expenditures devoted to land use or surface cover data gathering activities for water resource planning by federal and nonfederal agencies. This involved studying the budgets of the federal agencies provided by the Office of Management and Budget (1975, 1976a). The federal users who were considered and for whom benefit estimates were made are the Army Corps of Engineers, the Soil Conserviation Service, and the U.S. Geological Survey. Other, but smaller, federal water resource planning applications which were not considered were the Water Quality Administration, TVA, Bureau of Reclamation, Bonneville Power Administration, and the Forest Service.

Potentially large, but less certain benefits also appear possible in the activities of HUD and the EPA. Again it was not possible to obtain any definitive data from these agencies to make estimates during this study, so they were not considered.

At the regional, state and local levels, hundreds of agencies are current or potential users. An estimate of their total budget was built up by considering requirements at five different levels of local government.

The next major task was to estimate the fraction of the data gathering budget which could be impacted by Landsat technology. The method used was an expert judgement based on knowledge of the scope and nature of the work involved. This judgement was provided by Dr. Vincent V. Salomonson, head of the Hydrology and Oceanography Branch at Goddard Space Flight Center. His judgement was supplemented by conversations with experienced and knowledgeable federal agency personnel.

The final task was to estimate the actual savings in the impacted portion of the data gathering budget. Representative documented cases where remote sensing approaches had been compared to conventional approaches were used as guides and benchmark situations. These studies indicate that where data are being gathered and prepared for use in watershed models or water demand models, reductions in cost to do this job can go as high as 80 percent when a fully experienced group is doing the remote sensing data preparation (Ragan and Jackson, 1975; Ragan, 1976). In this report a 70 percent cost reduction factor was used. Where a simple inventory and display of land use or surface cover information was all that was needed, a 25 percent cost reduction was used. For more extended discussion of the applications and savings due to the use of remote sensing one should review the study report prepared by the Applications Survey Group Inland Water Resources Panel (1976).

In the last part of Section 5.3 the programs of the state and local agencies are discussed. The total land use and surface cover data collection budget, the fraction of the budget that could be impacted by Landsat data, and the fraction of that which could be saved by using Landsat data are estimated. This leaves aside future growth of the programs and counts nothing for the compounding of benefits that can often be achieved by reinvesting the cost savings in other parts of the programs. Results are therefore minimum benefit estimates.

5.3 Applications and Potential Benefits

Army Corps of Engineers

Four activities identified in the annual budget of the Corps of Engineers involve systems planning activities where savings could be achieved using Landsat data. The first of these is the "Urban Studies" program conducted under the budget category "General Investigations". About 30 studies are on-going at any one time, each covering the water problems of a metropolitan area and requiring about four years to complete. The total budget for these studies in currently $19 million per year, of which $3 to $4 million is used for data collection and interpretation. Landsat data could impact an estimated 25 percent of the data collection effort by providing land cover information needed for hydrological models, and save an estimated 50 percent of the cost of this information. See Table 5.1.

The second major category is the "Flood Plain Management" studies, also part of "General Investigations" and budgeted at $11.3 million annually. These studies provide detailed maps of flood-prone areas. The data collection

Table 5.1 Applications and Potential Benefits ($ Millions)

	Data Budget	LANDSAT Impactable Portion	Cost Savings
Army Corps of Engineers			
Urban Studies	3-4	.75-1.0	.37-.50
Flood Plain Management	2-3	1.0-1.5	.7-1.05
Hydrological Models	3	.75	.52
Advance Engineering and Design	5-6	1.0-1.2	.4-.48
Soil Conservation Service			
River Basin Surveys	2.5	.5	.25
Small Watershed Investigations	4-5	.6-.75	.3-.37
Snow Surveys	.75	.37	.25
Flood Hazards Investigations	1.0	.5	.35
Geological Survey			
Water Resources Investigations	50	2.5	1.2
Regional, District and Local Agencies			
Overall water planning, and planning of specific water resource projects	N.E.[1]	25.5[2]	17.8[2]
		33.4-34.6	22.1-22.8

[1] Not estimated. LANDSAT-impactable data costs estimated directly.

[2] These numbers include contributions toward these efforts by HUD, The Water Resources Council, EPA and other Federal agencies.

part of this budget represents $2 to $3 million annually, of which 50 percent is impactable with Landsat data. The estimated cost saving from using Landsat for the data would be 70 percent.

The third category is the hydrological modelling effort under "Research and Development", with a data budget of $3 million. About 25 percent of this is impactable with Landsat data, with a cost savings of 70 percent.

Finally, Advance Engineering and Design, budgeted at $27 million annually, has a data collection cost of approximately $5 to $6 million annually. This effort provides preliminary project designs and cost estimates. We estimate a Landsat impact of 20 percent, with a cost savings for this data of 40 percent.

Soil Conservation Service

Four programs are of principal interest.

The first is the "River Basin Studies" program which provides general surveys of water supply, water quality, erosion, sedimentation, flooding potential, irrigation and drainage and other agricultural needs of an entire river basin. Typically 50 to 60 of these studies are in process at any one time. About $2.5 million of the $16.4 million annual budget is used for data gathering, of which about 20 percent would be Landsat impactable. The cost savings potential is estimated to be 50 percent.

The Small Watershed Project Investigations and Planning program, budgeted at $13.6 million, provides studies of smaller areas with a greater level of detail in planning and design than is the case for "River Basin Studies". About 180 of these studies are now active, with several thousand awaiting funding. The estimated data collection portion of the budget is $4 to $5 million of which 15 percent is estimated to be Landsat impactable, at a cost savings potential of 50 percent.

The Soil Conservation Survey conducts a program of snow surveys to determine the water yield from the snow-pack in northern and western agricultural areas. The data gathering cost of this program is estimated to be $750 thousand annually. Landsat data is capable of impacting half this amount, with an estimated cost savings of 70 percent.

Finally, the Flood Hazards Investigations program, with a data gathering cost estimated at $1.0 million annually, offers the prospect of 50 percent impact with Landsat imagery. The estimated cost saving potential is 70 percent.

Geological Survey

The U.S.G.S. conducts a $56 million program of Water Resources Investigations to produce data and information relevant to flow and sediment discharge of rivers, location and quality of underground waters, and chemical quality and temperatures of water sources. The program includes research on water occurrence, water movement, the interaction of water with the environment, and techniques for measuring water data.

About 90 percent of the budget is spent for data gathering. However, because of the fact that physical samples are often needed, the Landsat impact would be less than in applications mentioned earlier. Five percent is used with a cost savings potential estimated at 50 percent.

Regional, District and Local Agencies

The University of Maryland (Inland Water Resources Panel, 1976) has conducted a study of regional, district and local activities in water resources planning and the analysis procedures are as follows.

The times required to complete individual tasks are extensive. There appear to be no data on the frequency of such studies on a national basis. In developing an estimate of the times and costs involved on a national basis a start was made by considering the 56 SMSAs that have populations in excess of 500,000. Within these SMSAs there are 174 county governments, 2,902 municipal governments, 1,470 township governments, 3,844 special districts, and an additional 2,486 special water-related districts dealing with flood control, water supply, drainage, etc. Experiences with the counties surrounding Washington, D.C. indicate that approximately 150 man-days per year are devoted to land cover determinations and parameter estimates associated with urban water resource developments. If an hourly rate of $8.00 is assumed, which would include overhead and fringe benefits, this would amount to $9,600 per year for each county. If it is further assumed that the 174 counties represent 75 percent of the work being done by all the counties in the nation, it would appear that county governments are expending approximately $2,230,000 annually. Within each of the SMSAs, there is probably a multicounty council of governments (COGs) organization which does major studies. These would be large areas of the 208 Study type. We assume that COGs are spending $26,880 per year, which would account for a $1 million annual expenditure by the 56 SMSAs. Municipal governments probable invest very little in this type of work. Therefore, we assume that the 2,902 municipal governments expend no more than 10 man-days per year, or $640 per organization. However, the municipal governments within the 56 SMSAs are a very small fraction of the national municipal governments. Therefore, we assume that the SMSA municipal governments account for only 25 percent of the national expenditure. Therefore, municipal governments, nationally, are spending in the vicinity of $7 million annually on studies that could be done by remote sensing. Township and special district governments probably represent a very small investment. If we assume they use no more than five days per year and, as before, that the SMSA units account for only 25 percent of the national, the expenditure by these township and special district governments would be in the vicinity of $4.9 million per year.

The water-related districts probably use in the vicinity of 30 man-days per year, or $1,920 per agency. It is probable that the water-related districts in the 56 SMSAs are substantially larger than those in the remainder of the national scene. Therefore, we assume that expenditures of the 2,486 districts within the 56 SMSAs account for 50 percent of the total annual expenditure. Therefore, $9.5 million is being expended annually by these organizations.

This analysis gives the total expenditures to be impacted as indicated below:

Counties	$2,230,000
Councils-of-Government	1,500,000
Municipal Governments	7,400,000
Township-Special Governments	4,900,000
Water-related Jurisdictions	9,500,000
	$25,530,000

Detailed studies which involve small watersheds are not suitable candidates for Landsat interpretation, and are excluded from the above figures. The large aggregate amounts cited above result from the numbers of jurisdictions, even though only a small number of days per year may be spent by any one jurisdiction in gathering the land cover data that Landsat can supply.

The case studies for the Anacostia Basin and in Northern Virginia referenced earlier in the Ragan and Jackson (1975) and Ragan (1976) studies indicate the cost savings that can be expected in typical regional and local planning studies. Both studies show that by using Landsat imagery, interpreted with commercially available automated classification systems, a cost savings of 70 percent can be achieved. We apply this 70 percent cost savings estimate to the $25.5 million now spent by regional, district and local agencies on obtaining and processing the types of data for which Landsat imagery would be suitable and the result is given in Table 5.1.

Estimates of all data collection and interpretation costs, the potential Landsat impact, and the likely degree of cost reductions are summarized in Table 5.1. The dollar values shown in Table 5.1 follow from the budgets and percentages discussed above. These estimates are minimal in the sense that the agency survey is not all-inclusive, and the benefits from earlier project completions or reinvestment of cost savings are not included. Furthermore, benefits derivable at the state level are not included, as no survey at this level has yet been completed.

6. WATER RESOURCES MANAGEMENT

6.1 Introduction and Summary

LANDSAT data can provide an important input to streamflow forecasts used in the management of dams and reservoirs. This input is the areal measurement of the snow cover in the local drainage basin. The snow cover information can improve flow prediction which in turn will effectively increase usable water for power generation and irrigation. The annual value of the improved information is $13-$41.6 million for basins in the western United States.

Three connections must be made to verify that LANDSAT can produce benefits in water impoundment. First, the area in a river basin which is covered by snow must be an important piece of information for the efficient management of reservoirs since snow-covered area is the data that LANDSAT can collect. Second, the use of LANDSAT data must improve streamflow forecasting capabilities since this is the mechanism for generating the benefits. Third, the results of the forecast improvement must be reduced to a dollar value.

6.2 The Snow-Covered Area Variable

The importance of snow-covered area to the accuracy of streamflow predictions has been based on a statistical analysis of 18 to 20 years of streamflow data and prediction errors for two river basins in California, the Kern and the Kings. The technical detail of this work is presented in the appendix to this chapter.

The analysis had two important conclusions. First, not all reservoir systems can profit from using LANDSAT snowcover data, but those that can will make significant reductions in the average level and variability of flow forecast errors. Second, the types of basins amenable to the use of snowcover data can be characterized by their general topography, the distribution of precipitation within the basin and the adequacy of the existing data presently used in forecasting. This second result allows the benefits obtained for the Kings and Kern River Basins to be extrapolated to California and then the western United States.

The first result was obtained independently by a group working within NASA and the private consulting firm Sierra Hydrotech. The second result is principally the work of Sierra Hydrotech. Having established the positive impact on forecasting errors for streamflow of a snow-covered area variable, the next link is the degree of impact that LANDSAT will create.

6.3 The Benefit Mechanism

Streamflow data is utilized by reservoir managers to adjust flood control safety margins. The accuracy of the streamflow has a direct bearing on the size of the margin. If an improvement in forecast accuracy occurs, then a dam manager can decrease his flood reservoir space in the reservoir and he can also better regulate spillage from the dam. The net result of such activities is an increase in the usable water at the dam. The value of the extra water is created as it is used either in the generation of electricity or in irrigation of agricultural land.

6.4 Capabilities

The analyses performed on the streamflow forecasts for the Kern and Kings Rivers in California indicated that the inclusion of snow-covered areas as a variable with an accuracy attainable by the LANDSAT/Thematic Mapper system had the following impact. The mean error of forecast is reduced approximately 30 percent and the variability of the error is reduced by about 10 percent for the Kern River. The inclusion of snow-covered area did not result in a reduction of forecast error or in the variability of the error for the Kings River Basin. The details of these determinations are shown in a Technical Appendix.

Sierra Hydrotech investigated the differences between the Kings and Kern basins to discover what factors characterize those basins as amendable or not amendable to forecast improvement through use of LANDSAT data. Basins where improvement will occur can be described by the following:

- Topography - Inhomogeneity of the distribution of area with elevation
- Precipitation Distribution - Uneven distribution of the amount of precipitation with elevation
- Poor quality of existing precipitation data.

By classifying all the other river basins in California by these criteria into the two classes which are exemplified by the Kern and Kings Rivers, the capabilities derived above can be extrapolated to the entire state of California. Expressed in terms of an increase in usable water, LANDSAT data with Thematic Mapper accuracy will produce approximately a 185,000 acre-foot increase anually for the state of California. Sierra Hydrotech and Dr. A. Rango of NASA/GSFC carried out the extrapolation. The details are in the appendix.

An approximate extrapolation to eleven western states was carried out by Dr. Rango. He classified the states into groups, each of which was hydrologically similar to California. The groups were:

- Arizona, Utah and Nevada
- New Mexico and Colorado
- Wyoming and Montana
- Washington, Oregon and Idaho.

The extension of the capabilities to the western United States was then refined on the basis of relative cloud cover, climatology and irrigation/hydropower activity among the groups. The extrapolation factors developed are 2.31 for irrigation and 6.41 for hydropower. A detailed discussion of the derivation of the extrapolation is in the appendix.

6.5 Benefits

The last step in the development of the benefits of LANDSAT data to water resources management is the imputation of a dollar value to the increase in usable water that results from the improved flow forecasts. Since there are two major uses for the water, its value is dependent upon its ultimate use.

To determine the value of irrigation water, an average cost per acre-foot of water for the California Aqueduct was computed. The Department of Water Resources of California provided the required information in its Bulletin No. 132-75 and the figures are presented in the appendix. Weighing the costs at each juncture of the aqueduct by the volume of water estimated to be delivered to that juncture in 1976, an average cost of irrigation water of approximately \$60 per acre-foot was derived.

The value of an acre-foot of water used in the generation of electricity was approximated using a conversion factor of the energy value of the water to an equivalent amount of oil. The factor used was obtained in conversations held at the California Department of Water Resources. It was one acre-foot of water $\approx$ 10 barrels of oil. Conservatively valuing oil at \$5 per barrel gives an acre-foot value of \$50 for hydropower usage.

Due to the nature of reservoir operations, it is unlikely that all of the increase in usable water resulting from improved flow forecasting would be captured for economical use. In discussions between Sierra Hydrotech, the California Department of Water Resources and Dr. A. Rango of Goddard, an efficiency figure of .5 was agreed to as best approximation.

The computation of the benefits is now straight forward.

IRRIGATION

Value for California = (Increase in volume in acre-foot) x (value per acre-foot) x efficiency factor

= 185,000 A.F. x $60/A.F. x .5 = $5.5M

Value for West = $5.5M x 2.31 = $12.7M

HYDROPOWER

Value in California = Increase in volume) x(Value/A.F.) x efficiency factor

= 185,000 A.F. x $50/A.F. x .5 = $4.5M

Value in West = $4.5M x 6.41 = $28.9M

Since some but not all the increase in water can be used for both hydropower generation and irrigation due to timing incompatibilities, the actual value of the benefit must be between that obtained if only one use is considered and if both uses are considered. That is, the benefit for improved flow forecasts due to LANDSAT data is in the range $12.7M to $41.6M.

6.6 Other Benefits

The benefits that were quantified in this section were based solely on the hydropower generation and irrigation applications. There are clearly additional uses for water, however, we were unable to compute the associated benefits within the constraints of this study. For informational purposes the major benefit areas which have not been quantified are flood control, recreation, navigation, and domestic and industrial water supplies.

TECHNICAL APPENDIX

TECHNICAL RATIONALE FOR SNOW-COVERED AREA

This section presents the rationale for translating snow-covered area measurements into improvements in forecast accuracy and water usage revenue.

Snow-covered Area Importance

The melting of the snowpack in the Spring is the source of greater than 50 percent of streamflow in most areas of the western United States (Committee on Polar Research, 1970 and Rooney, 1969). For example, about 75 percent of the runoff in the Colorado River originates from snowmelt in key basins that represent only 13 percent of the contributing land area (U.S. Department of Interior, 1970). The early prediction of the amount of runoff to be derived from the snowpack allows more efficient utilization of the limited water supply for power generation, irrigation, flood control, domestic and industrial water supplies, and recreation. Historically, the Soil Conservation Service has prepared seasonal snowmelt runoff forecasts for western river basins that have been extremely useful for water management purposes. For the western United States, error in seasonal runoff forecasts prepared on April 1 ranges from 7 to 40 percent, with an average of approximately 18 percent (U.S. Department of Interior, 1974).

These discrepancies are due to forecasting errors inherent in the procedures used and to errors resulting from variations in the weather after April 1. The forecasting errors result from uncertainties in point measurements of snow water equivalent which are commonly used as indices of basin-wide snowmelt runoff in prediction equations. The errors in predicted runoff tend to be largest in years of unusually heavy or light snowpack accumulation.

Observations of the areal extent of the snowpack have long been recognized as an important (but difficult to obtain) hydrologic parameter related to both the average snowpack water equivalent and the snowmelt-derived runoff. The U.S. Army Corps of Engineers (USACE) in the Northwest and the Salt River Project in Arizona have in the past flown low altitude missions in order to measure snow cover areal extent to aid in their runoff prediction responsibilities. The rate at which the snow cover depletes is an index which is inversely related to the snow water equivalent and the generated snowmelt runoff. As the snow leaves the low elevations of the watershed, the hydrograph begins to rise and continues to do so until the snowpack area reaches a critical value where meteorological snowmelt conditions cannot produce ever increasing amounts of runoff. The hydrograph then begins to recede until the remaining snowpack disappears and the runoff is maintained by baseflow. The slower the snowline retreats up the watershed to the elevation where the hydrograph starts a downward trend, the greater the resulting runoff volume and, usually, peak flow.

By knowing the snow-covered area, the area of the watershed representative of conventional snow water equivalent measurements can also be inferred. This allows the objective extrapolation of water equivalent values over an entire watershed rather than a rough approximation obtained by a single arithmetic averaging. Further refinement permits the combination of water equivalent and snow-covered area data to calculate existing snow volume by elevation zones. Such determinations are required by various numerical models and permit the most sophisticated use of snow-covered area for runoff predictions. By more accurately characterizing and locating the available snow water volume, remote sensing derived snow-covered area measurements can be used to improve forecasts of seasonal flow. A study on the Kings and Kern River watersheds in California was conducted so as to show the magnitude of possible forecast improvement on two dissimilar basins as a result of the incorporation of SCA into forecast procedures.

The fact that snow-covered area can reduce standard error of forecasts when included in prediction procedures becomes important in conservation and availability of water. When water operators and users are assured of a more accurate snowmelt runoff forecast, more multiple uses of the existing water supply are possible. Hence, the water supply is effectively increased. For example, a portion of water that would normally be held in a reservoir for late season irrigation or power requirements could be released for early season irrigation or domestic supplies because the reservoir operator would be more confident that additional water would be forthcoming. Additional revenue would consequently result when more of the existing supply was utilized.

In order to test how much of an improvement in forecast accuracy might result from the use of snow-covered area data, the two watersheds in California were tested. Both the Kings and Kern Rivers in the Southern Sierras had relatively long-term aircraft snow-covered data (18-20 years) in addition to the full complement of conventional data. The conventional data were obtained from the Snow Surveys Branch of the California Department of Water Resources and the aircraft snowcover data from U.S. Army Corps of Engineers. Conventional techniques for the prediction of seasonal flow on both watersheds were examined and the aircraft snow-covered area data were combined with the conventional data set for each available year. Various techniques for incorporating snow-covered area into the conventional prediction methods were investigated. The general approach was to include snow-covered area with various combinations of conventional parameters in regression analyses and compare the results of predictions for certain control years with techniques not using snowcovered area.

This study was initiated for the purpose of determining the impact of snow-covered area, as mensurated by LANDSAT, on forecasting seasonal streamflow. The Kern and Kings River basins in California were analyzed in detail. The conclusion of the study was that including snow cover data in the water runoff model reduced the average error of the Kern River basin forecast by 29 percent and the standard deviation of the errors by 8 percent, while the forecast error and standard deviation of the errors of the Kings River basin remained at approximately their current level. These studies are discussed in the following.

The California Department of Water Resources supplied eighteen years of data for the following variables for the Kern River basin:

Y = April-July Runoff
X_1 = April 1 High Elevation Snowpack Index
X_2 = October-March Precipitation Index
X_3 = Previous Year April-July Runoff
X_4 = April-June Precipitation Index
X_5 = April 1 Low Elevation Snowpack Index
X_6 = May 1 Snowpack Index
X_7 = May 1 Snowcovered Area in Precent of Basin.

The model currently being used does not use snowcover data; it is of the form $Y = AX_1X_2+BX_3+CX_4+DX_5+EX_6+F$.*

A new model utilizing snow cover data, $Y = AX_2X_7+BX_1+CX_6+D$, was found by using a step-wise regression analysis on the given data and various combinations of the data. The statistics for the two models are:

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*A,B,C,D,E,F are regression coefficients.

	Current Model	Snow Cover Model
R^2 Value	97.9	98.4
F-test Value	156.0	355.3
Standard Error of the Estimate	35.6	30.5

Both models were exercised to determine which would provide the better forecast. Since the number of available data points was limited and several variables were being considered, a series of regressions were used to make the forecasts. This technique consisted of deleting the year to be forecasted from the data base, deriving the regression equation from the remaining data, and then making a forecast for the deleted year. The absolute value of the difference between the forecast and the actual runoff represented the error of the forecast. The forecast and forecast error were then computed for each year. The average and the standard deviation of the errors were calculated, resulting in the following table:

	Current Model	Model with Snow Cover Data	Improvement
Average Forecast Error	40.11	28.67	29%
Standard Deviation of Forecast Errors	25.28	23.31	8%

The snow cover model has two terms not in the current model--the variable with snow cover data included and the April 1 high elevation snowpack index variable used alone. To be certain that it is the variable with snow cover data, and not the snowpack index variable, causing the improvements, two tests were made. First, the current model with the snowpack index variable added (FORM I) was run and showed that this addition to the current model would not result in the improvements noted above. In addition, step-wise regression analysis was applied to the given data and various combinations of the variables, excepting those involving snow cover data. A model (FORM II), $Y = AX_1X_2+BX_6+C$, resulted. These two models were each exercised using the forecasting technique described above. In both cases the model with snow cover data gave better results as seen from the table below:

	Form I	Form II	Model with Snow Cover Data
Average Forecast Error	38.33	35.67	28.67
Standard Deviation of Forecast Errors	27.01	27.29	23.31

The same type of analysis was done with data for the Kings River. The Department furnished twenty years of data for the following variables:

Y = April-July Runoff
X_1 = April 1 Snowpack Index
X_2 = October-March Precipitation Index
X_3 = Previous Year April-July Runoff
X_4 = April-June Precipitation Index
X_5 = May 1 Snow-covered Area in Percent of Basin.

The model which is now used by the department is:

$$Y = AX_1+BX_2+CX_3+DX_4+E.$$

The regression study of the variables selected a model that incorporated the snow cover data; it is: $Y = AX_4+BX_2+X_5+C$. The statistics of the two models are:

	Current Model	Snow Cover Model
R^2 Value	97.1	95.9
F-test Value	161.3	218.4
Standard Error of the Estimate	120.9	145.7

For the reasons noted above, both models were run using the series of regressions for forecasting. In this river basin the addition of snow cover data did not improve the forecasts. Both the average error and the deviation of the forecast errors remained at the present level.

	Current Model	Model with Snow Cover Data
Average Forecast Error	114.9	120.9
Standard Deviation of Forecast Errors	106.4	107.7

The logical question now is why does snow cover data bring about an improvement in forecast accuracy in the Kern River basin but not in the Kings River basin. The explanation is discussed in the following section.

Although there has been no exhaustive research regarding the relatively better performance of the Kern River procedures compared to the Kings River procedures, the following are suggested as probable causes. These probable causes might represent criteria for selecting watersheds where areal extent of snow cover might prove a valuable parameter in reducing forecast error as the snowmelt season progresses.

1. <u>Inadequate or unrepresentative precipitation data</u>. Precipitation during the snowmelt season is probably measured less representatively on the Kern River than on the Kings River. April precipitation, averaging over 10 percent of the seasonal total, may possibly be partially described in terms of areal extent of snowcover as the melt season progresses. It is suggested that watersheds which lack adequate or representative late season precipitation measurements might benefit from areal extent of snow cover.

2. <u>Topography</u>. The Kings River distribution of area which elevation is relatively homogeneous with areas between 6 and 12 thousand feet distributed uniformly (Figure 6.1). Average April 1 snowline on the Kings is 6500 feet. The Kern River, with an average April 1 snowline of 7000 feet (Figure 6.2), appears to have a substantial portion of the area between 7 and 9 thousand feet. It is suggested that watersheds with relatively large portions of the area confined to given elevation zones may respond more readily to analysis utilizing areal extent of snow cover.

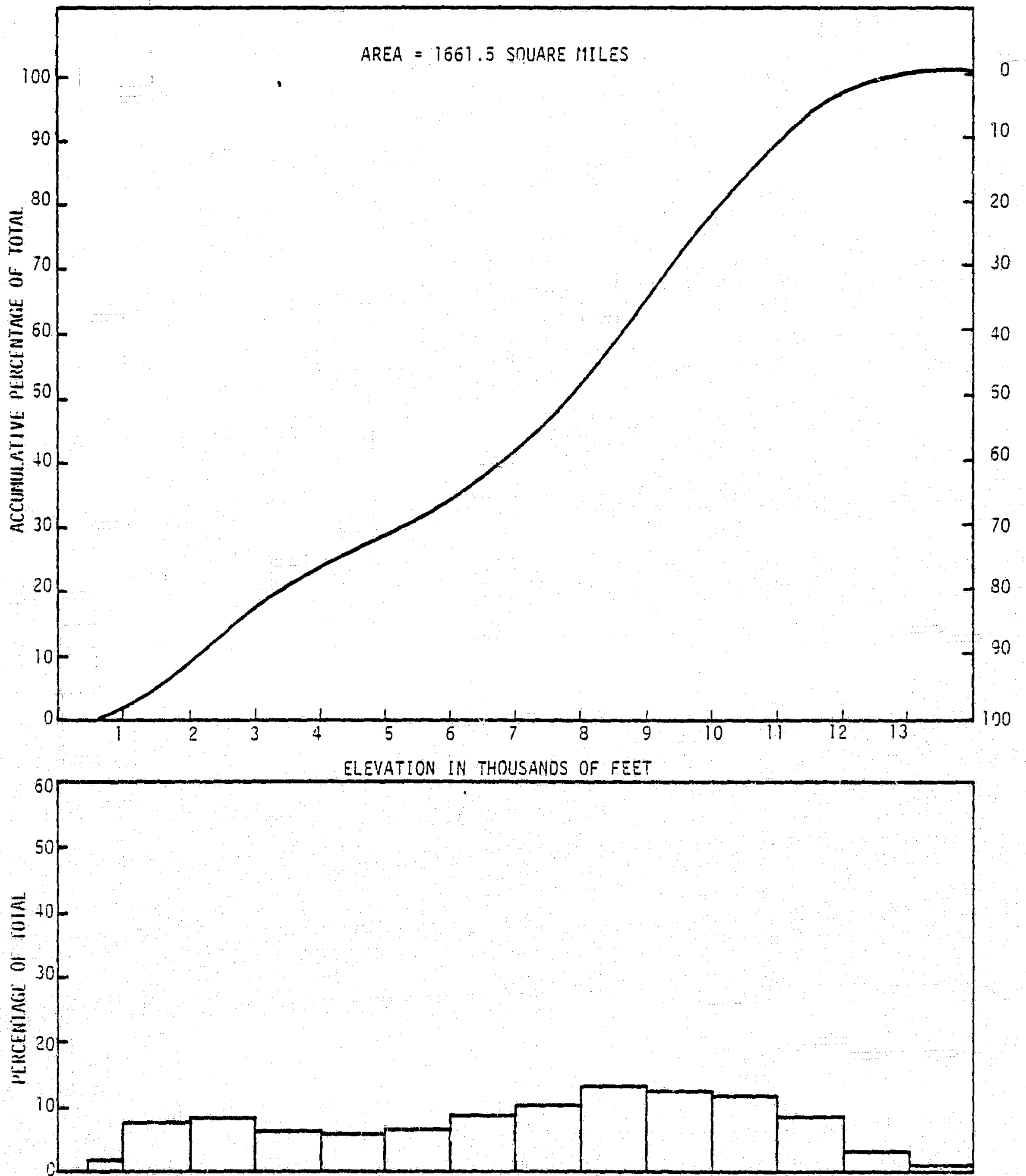

Figure 6.1 Kings River at Piedra

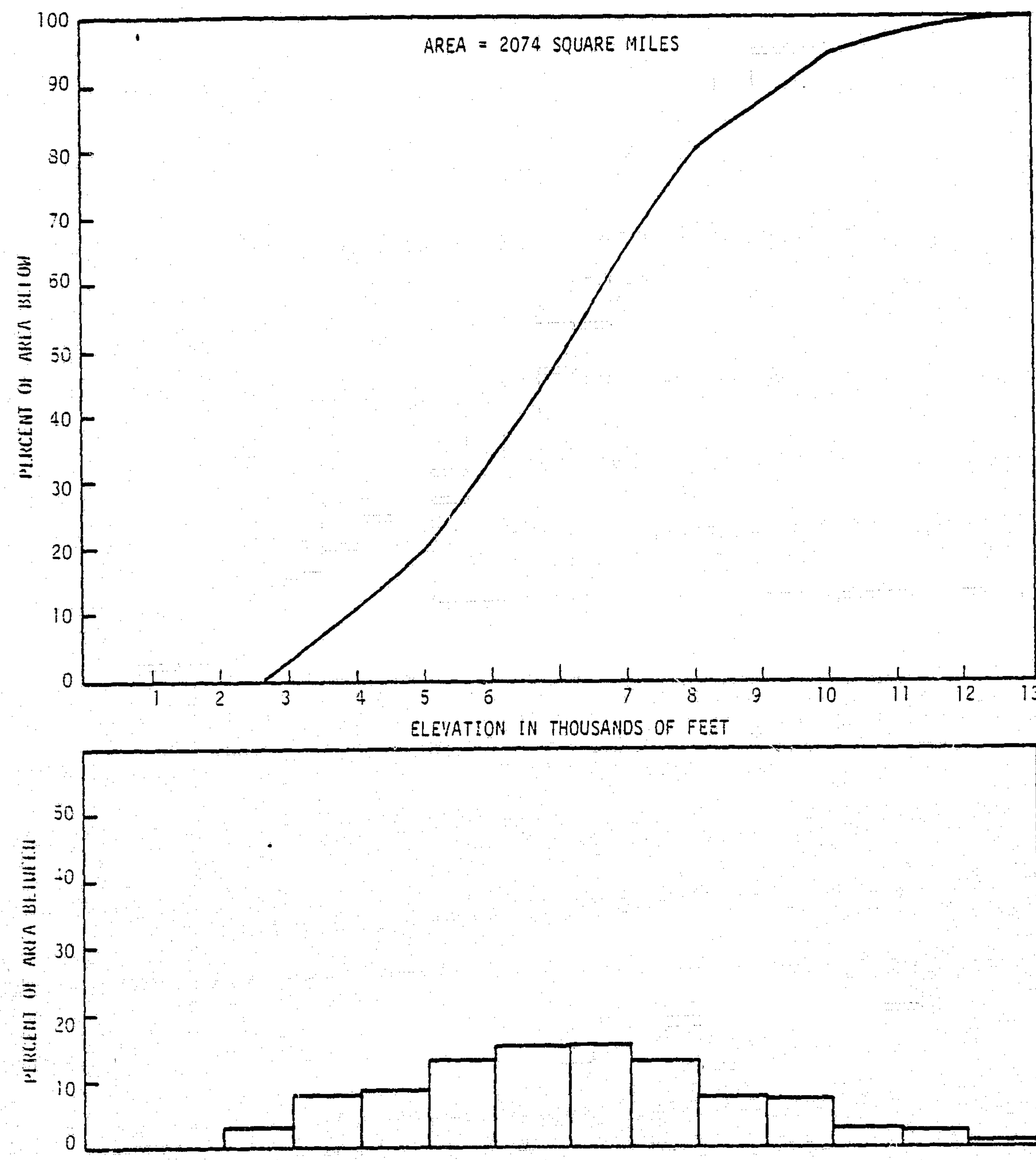

Figure 6.2 Kern River Inflow to Isabella

3. Precipitation Distribution. The Kings River apparently has a relatively uniform distribution of precipitation with elevation. The Kern River, on the other hand, may have average annual precipitation of 40 inches or more at 9000 feet in one portion of the basin and as little as 15 inches at the same elevation in other portions of the basin. This distribution may vary considerably from season to season. It is suggested that areal extent of snow cover as the melt season progresses may provide an index to the distribution of precipitation and snowpack quantities throughout the basin.

The combination of precipitation distribution and area-elevation distribution in a given watershed could provide an index to the probable effect of areal extent of snowcover in updating forecasts of runoff volume. Spareseness of other data types might also be a consideration.

Other major water yielding basins in California were investigated in regard to these possible causative parameters. The area/elevation plots of some of these watersheds are shown in Figures 6.3-6.11. Based on the same considerations used for explaining the Kern/Kings difference, it was estimated that snow-covered area would be a major factor in reducing snowmelt runoff forecast error on at least 11 of 22 major basins in California as shown in Table 6.1. The standard error can be decreased for May 1 forecasts on the order of 170,000 A.F. in California using snow-covered area. If a 9-day coverage from the Thematic Mapper is available, a small improvement (about 10 percent) in forecast accuracy could be realized increasing the total to about 185,000 A.F. It is further estimated that 50 percent of this decreased standard error or about 92,500 A.F. of usable additional water annually can be realized by more efficient utilization as a result of improved forecasts in California. This water can be used for either irrigation and/or power.

To allow extrapolation to the entire eleven western states, state groupings were constructed that could be compared to California on the basis of cloud cover and climatology. The cloud cover and climatology considerations

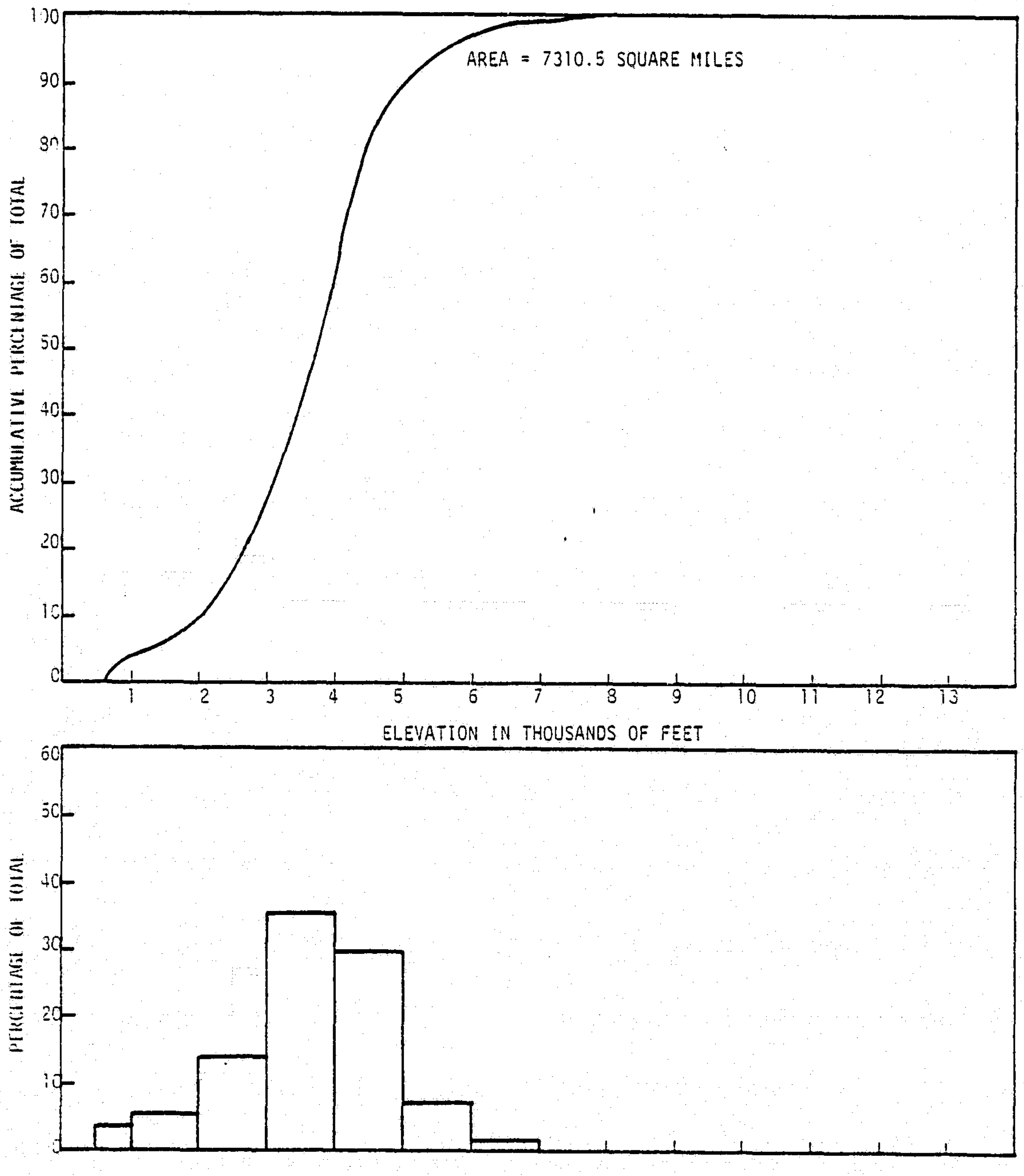

Figure 6.3 Sacramento River Inflow to Shasta Reservoir

ERRATA SHEET

RE: ECON Report 76-102-3, Contract NASW-2558, September 15, 1976
"A Cost-Benefit Evaluation of the LANDSAT Follow-on Program"

p.3-5, line 19:	Change "not" to "note"
p.3-26, line 14:	Change "planting" to "harvesting"
p.3-32, line 19:	Change "14.9" to "149"

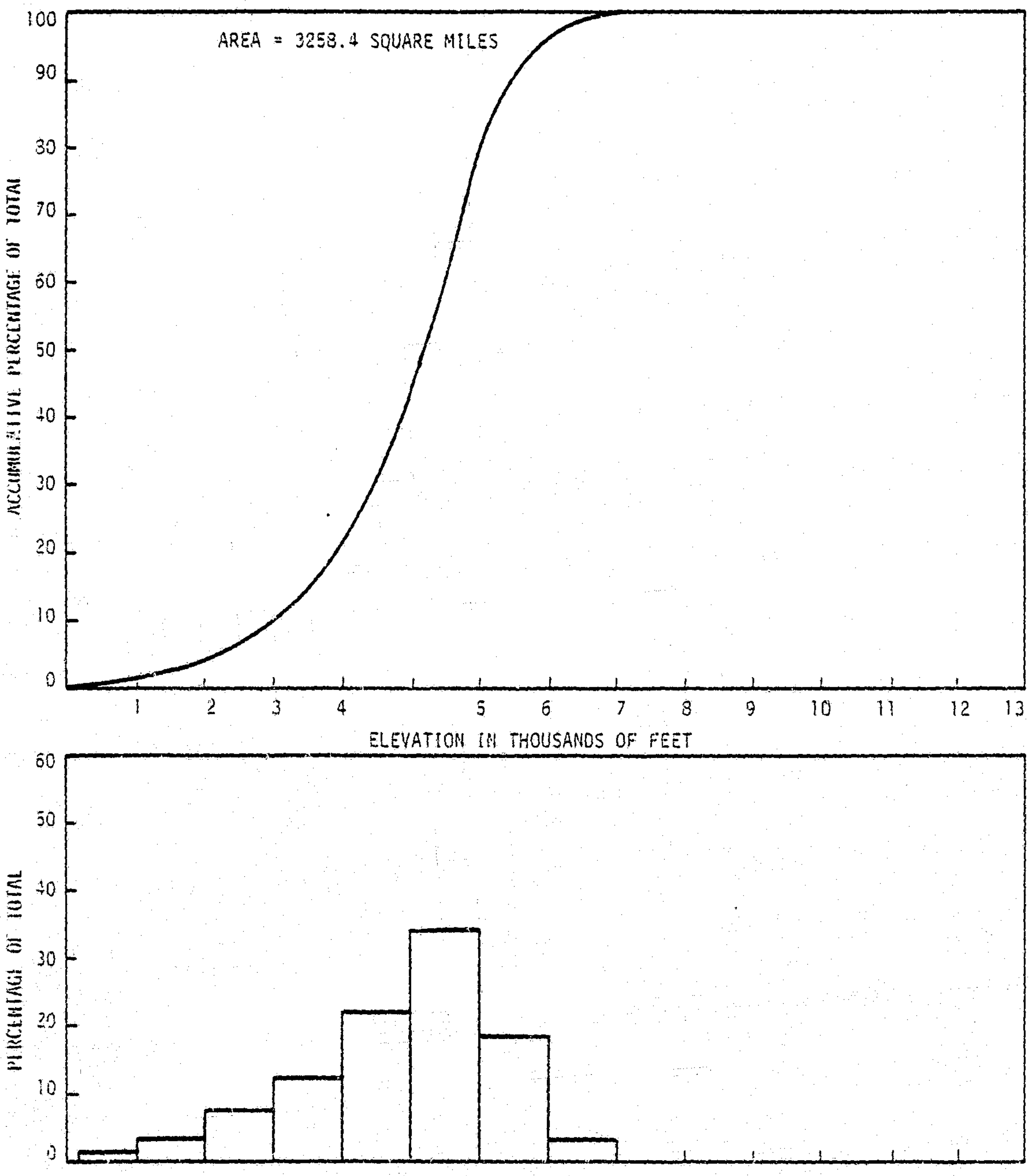

Figure 6.4 Feather River at Oroville

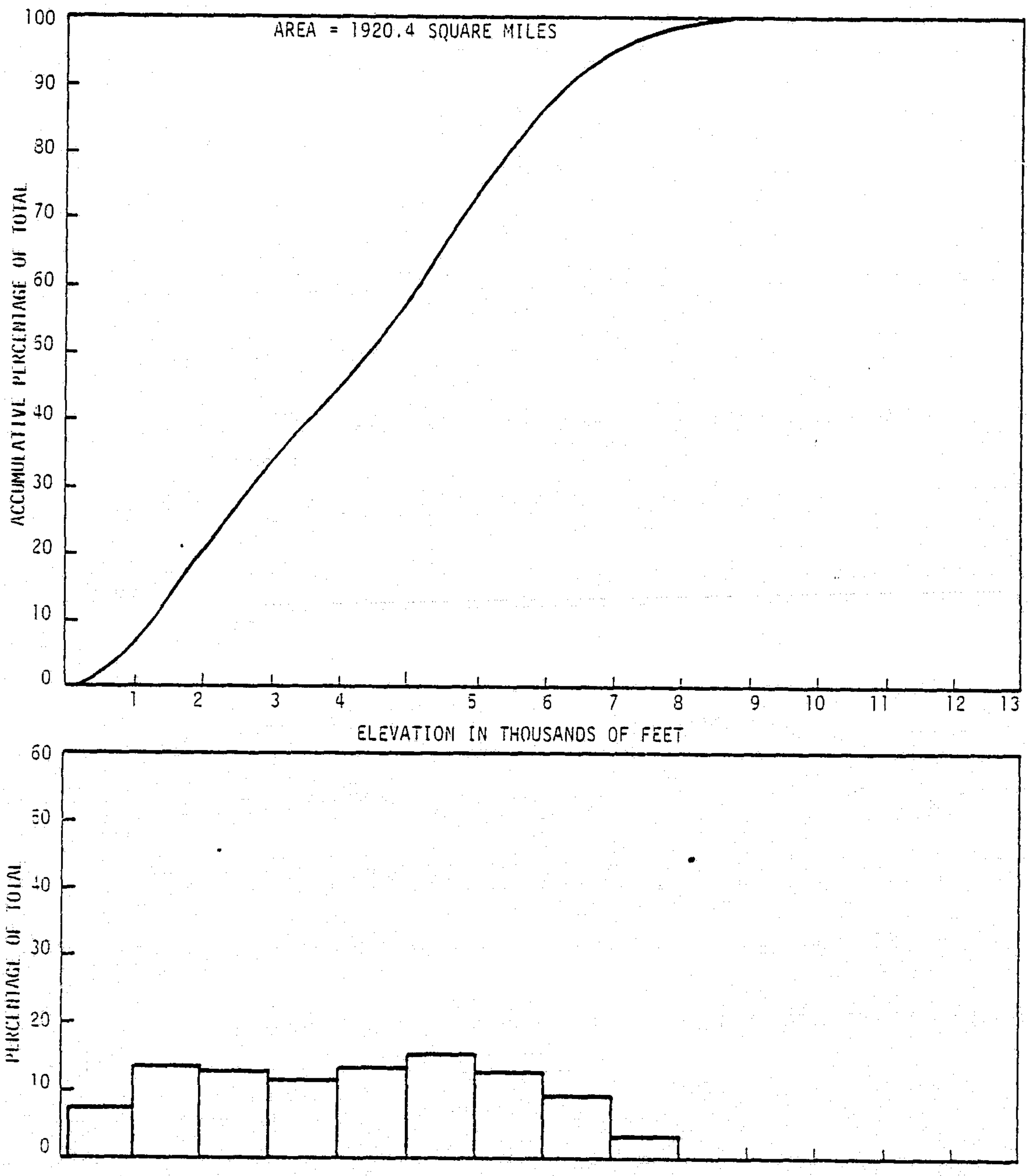

Figure 6.5 American River at Fair Oaks

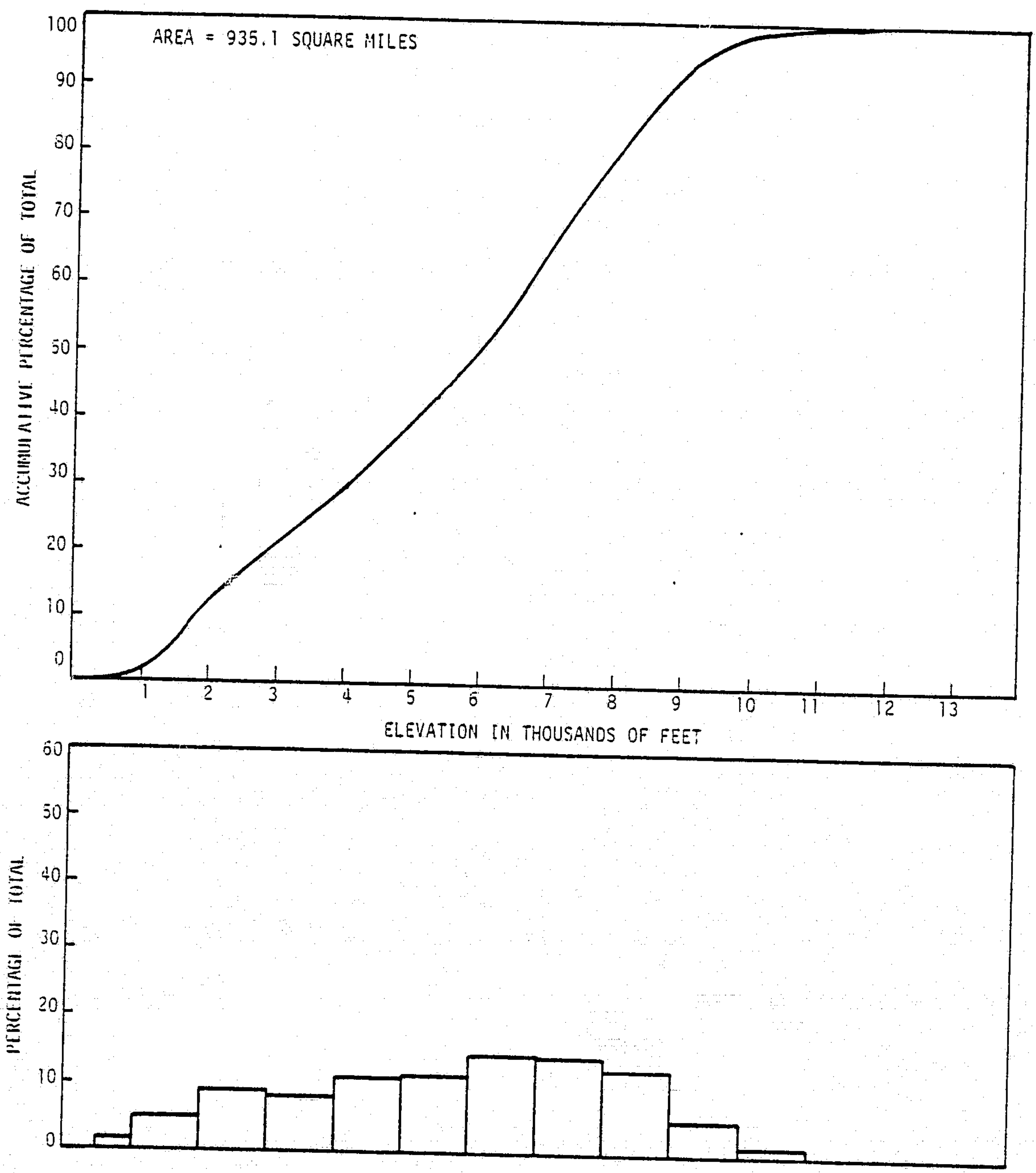

Figure 6.6 Stanislaus River Below Melones Power House

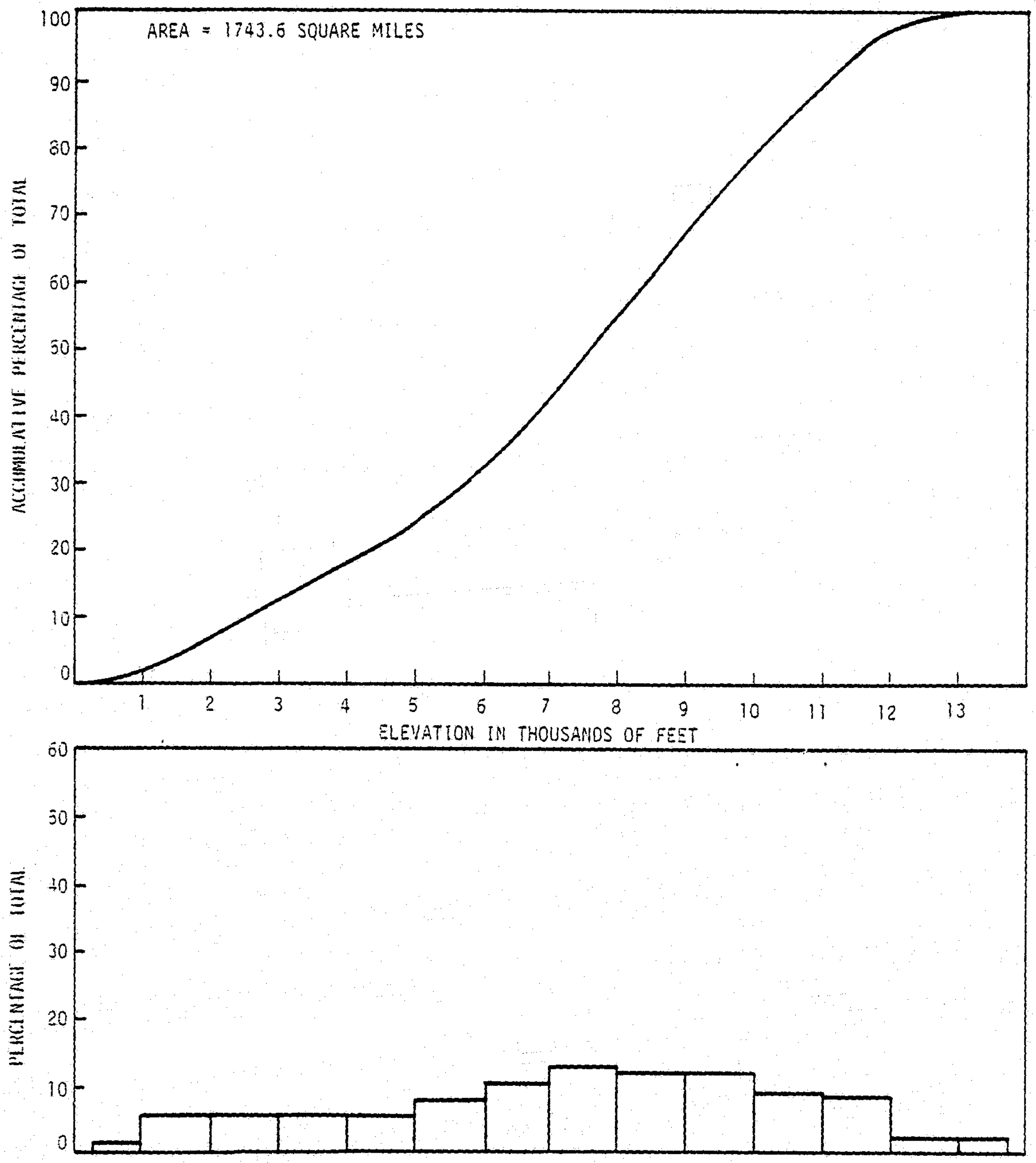

Figure 6.7 San Joaquin River at Friant

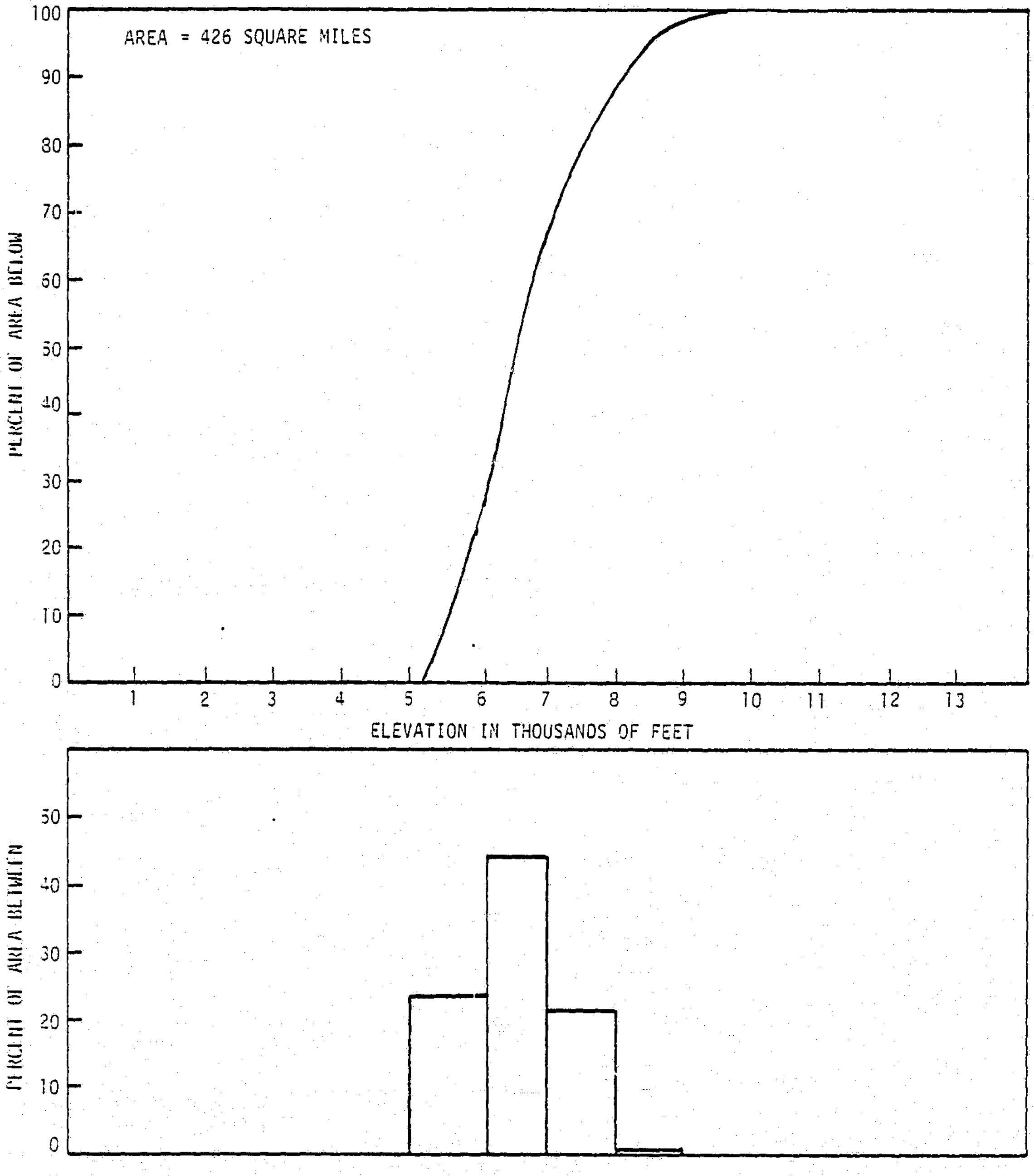

Figure 6.8 Truckee River - Tahoe City to Farad

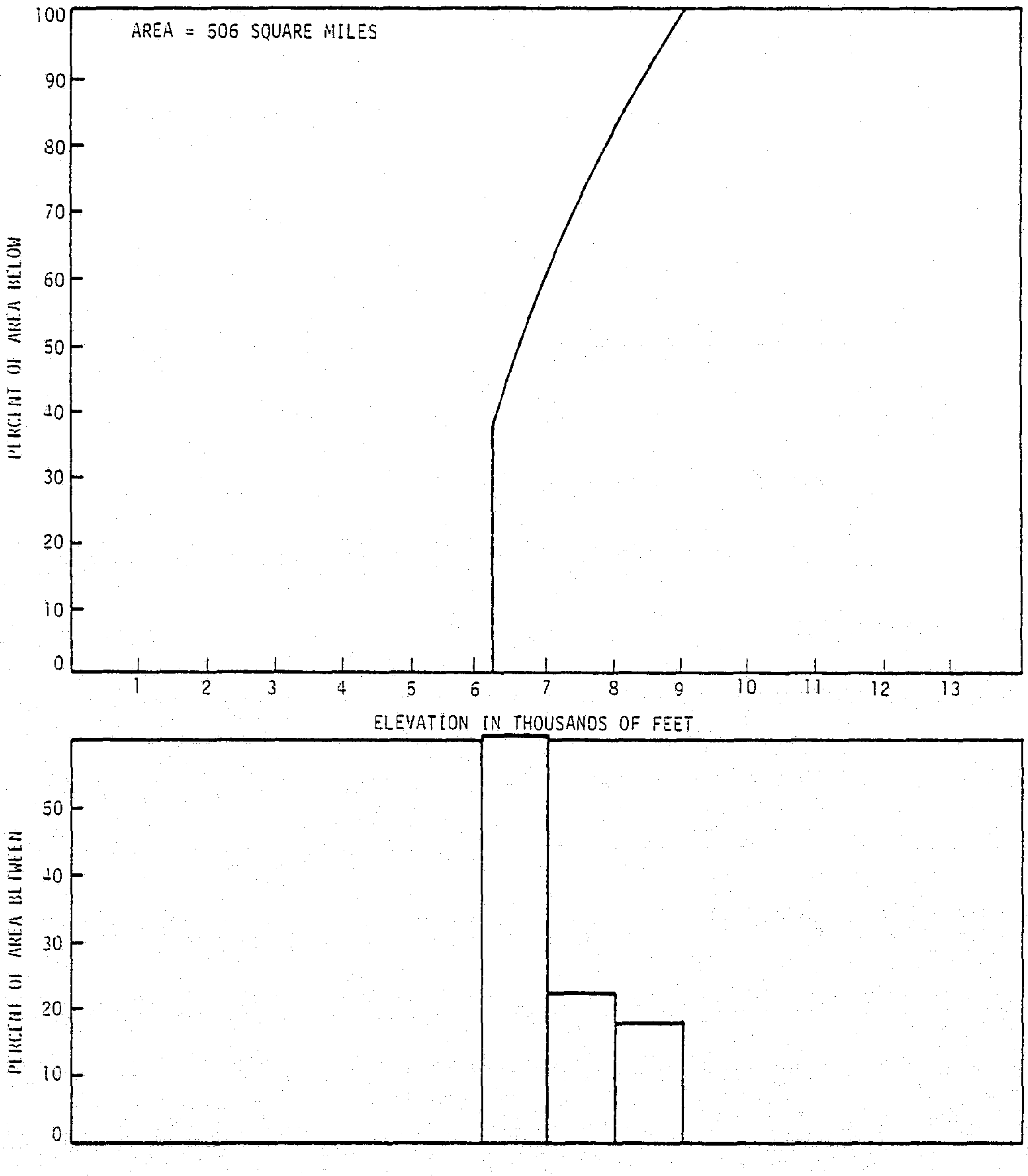

Figure 6.9 Truckee River at Tahoe City

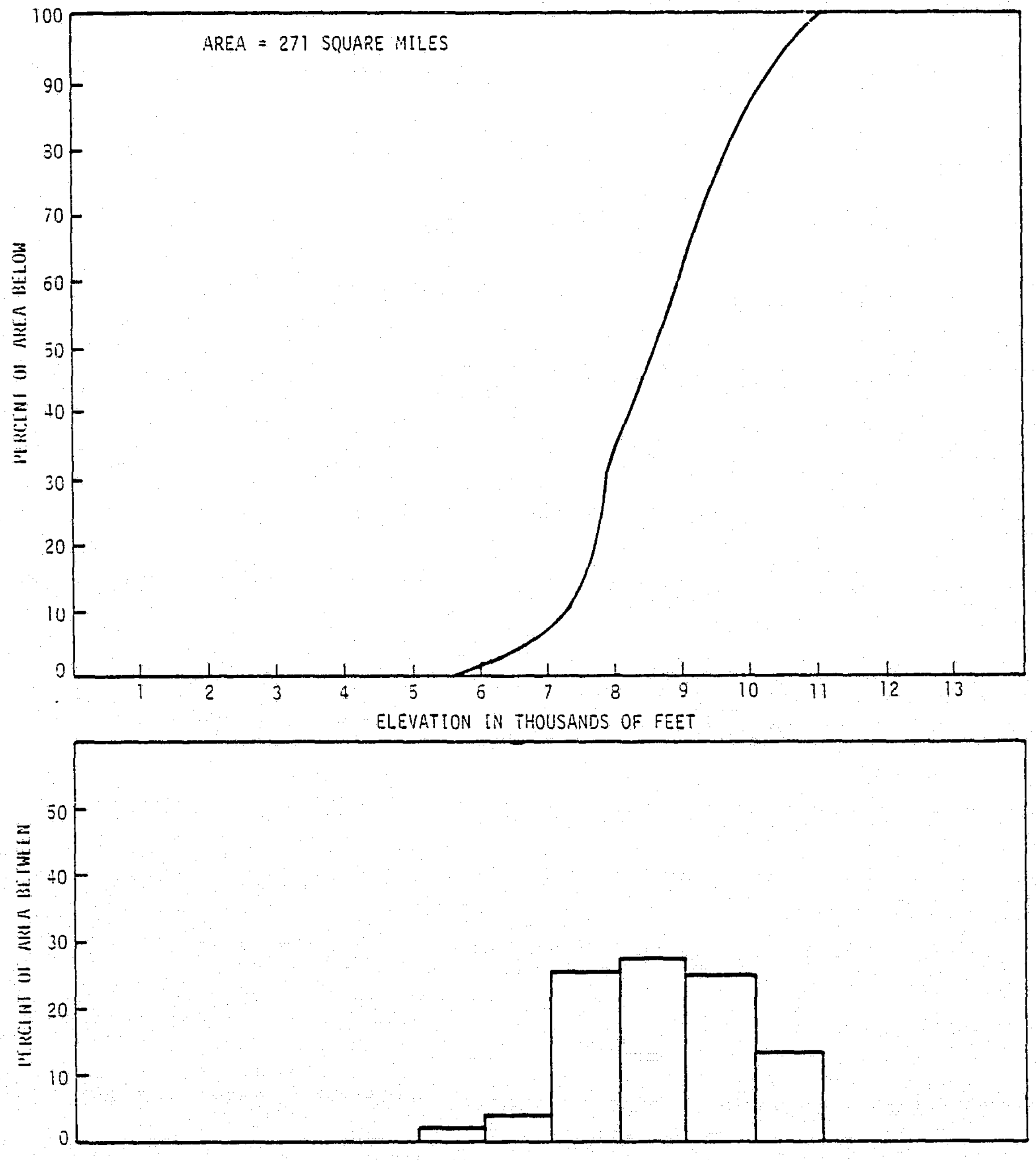

Figure 6.10 West Walker River near Coleville

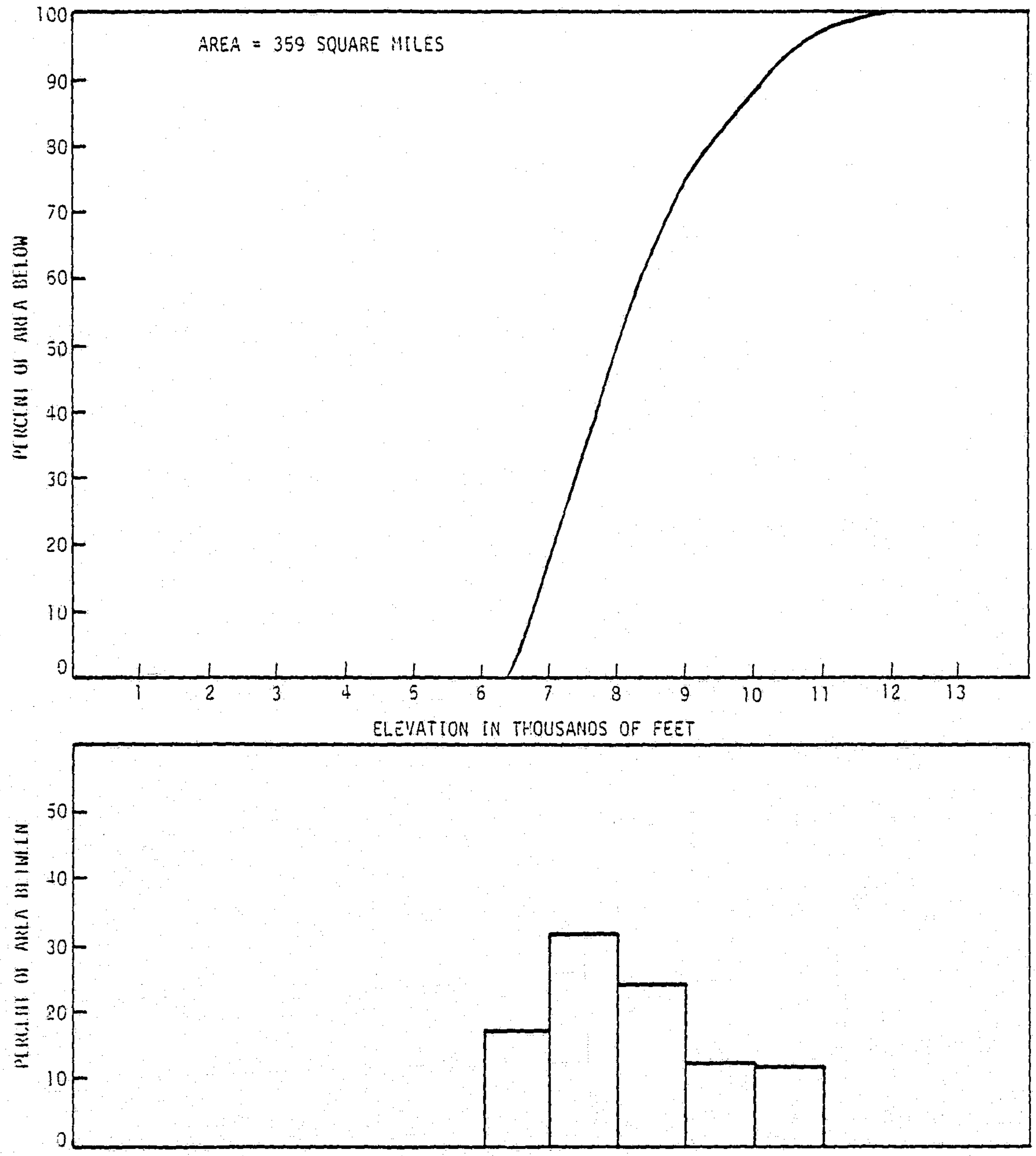

Figure 6.11 East Walker River near Bridgeport

Table 6.1 Estimates of Increased Forecast Accuracy for Forecasts by CDWR Based on May 1st Update, June 28, 1976

Stream	Average Apr-July Runoff AF	Standard Error 1000 AF	Standard Error %	Estimated Decrease S. E. %	Estimated Decrease S. E. 1000 AF	Estimated Decrease S. E. % A. S.	Remarks
Trinity	617.3	41.6	6.7	15.	6.2	1.0	
Sacramento:							
Sacramento	285.0	28.4	10.0	30.	8.5	3.0	
McCloud	420.0	46.0	10.9	30.	13.8	3.3	Likely prospect for large base flows
Pit	1,013.0	95.0	9.4	30.	28.5	2.8	
Feather	1,862.0	179.0	9.6	30.	53.7	2.9	
Yuba	1,081.0	77.4	7.2	15.	11.6	1.1	
American	1,321.0	78.0	5.9	15.	11.7	.9	
TOTAL	5,982.0	503.8	8.4		134.0	2.2	
San Joaquin:							
Mokelumne	466.0	22.8	4.9	0	0	0	
Stan Islaus	717.0	47.4	6.6	0	0	0	
Tuolumne	1,236.0	55.6	4.5	0	0	0	
Merced	608.0	40.9	6.7	0	0	0	
San Joaquin	1,193.0	68.0	5.7	0	0	0	
TOTAL	4,220.0	234.7	5.6				
Tulare Lake:							
Kings	1,157.0	71.7	6.2	0	0	0	Test Watershed
Kaweah	270.0	20.6	7.6	0	0	0	
Tule	59.0	9.1	15.4	?	?	?	
Kern	420.0	43.2	10.3	40.	17.3	4.1	Test Watershed
TOTAL	1,906.0	144.6	7.6		17.3	1.0	

Table 6.1 Estimates of Increased Forecast Accuracy for Forecasts by CDWR Based on May 1st Update, June 28, 1976 (continued)

Stream	Average Apr-July Runoff AF	Standard Error 1000 AF	Standard Error %	Estimated Decrease S. E. %	Estimated Decrease S. E. 1000 AF	Estimated Decrease S. E. % A. S.	Remarks
<u>Sierra East Side</u>:							
Truckee	309.0	20.4	6.6	30.	6.1	2.0	High Eastern
Tahoe	174.0	12.0	6.9	15.	1.8	1.0	Portion Dry
West Carson	51.0	2.6	5.1	15.	.4	.8	
East Carson	181.0	18.4	10.2	30.	5.5	3.0	High Eastern
West Walker	143.0	8.4	5.9	15.	1.3	.9	Portion Dry
East Walker	60.0	11.7	19.5	40.	4.7	7.8	
TOTAL	918.0	73.5	8.0		19.8	2.1	

were used to develop empirical factors that expressed the likelihood of LANDSAT realizing the benefits in each of the state groupings that were estimated in California. California was given an empirical factor of 1.00. The state groupings and their cloud cover and climatological empirical factor are as follows: 1) Arizona, Nevada, and Utah (1.15); 2) Colorado and New Mexico (0.85); 3) Wyoming and Montana (0.50); and 4) Idaho, Washington, and Oregon (0.33).

To compare the importance of irrigation and hydropower in California with the rest of the West and thus provide a basis for extrapolating the California benefit estimates, state group withdrawals for irrigation and hydropower were compiled from van der Leeden (1975). The total withdrawals for each group were multiplied by the cloud cover and climatology factor and compared to the California irrigation or hydropower withdrawal as shown in Table 6.2. Totaling the rest of the West and comparing it to California, irrigation relative importance is 1.31:1 and hydropower relative importance is 5.41:1. These conversion factors, developed on the basis of cloud cover and climatology and the importance of irrigation and hydropower, are used to extrapolate the California benefits to the remaining western states.

The computation of the value of water used for irrigation purposes is based on figures presented in Bulletin No. 132-75 of the California Department of Water Resources. The unit dollar figure obtained is a weighted average of costs to all the reaches of the California Aqueduct. The cost at each reach is weighted by the volume of water delivered to the reach. Table 6.3 presents the figures used for each reach of the Aqueduct, the volume of water delivered, cost per acre-foot and the total cost.

Table 6.2 Total Water Withdrawals by State Group				
State Group	Average Irrigation Withdrawal (MGD)		Average Hydropower Withdrawal (MGD)	
	Actual	Corrected*	Actual	Corrected*
A. California	33,000	33,000	84,000	84,000
B. Arizona, Nevada and Utah	13,000	14,950	27,000	31,050
C. Colorado and New Mexico	16,000	13,600	5,000	4,250
D. Montana and Wyoming	13,000	6,500	76,000	38,000
E. Idaho, Oregon and Washington	25,000	8,250	1,154,000	380,820

*Corrected on Basis of Cloud Cover and Climatology.

Table 6.3 Water Volume, Costs and Total Costs by Reach

Reach	Water Volume (AF)	Costs/AF	Total Costs
1	590	$ 22.07	13,021
2	0	29.49	0
3	2,700	97.81	264,087
1	265	24.29	6,437
2	5,444	25.18	137,080
4	2,894	27.56	79,759
5	2,026	32.03	64,893
6	6,571	32.26	211,980
7	12,526	34.05	426,510
8	8,774	36.67	321,743
9	88,000	42.11	3,705,680
2A	3,500	6.16	21,560
8C	29,500	11.46	338,070
8D	58,100	11.82	686,742
9	35,100	12.09	424,359
10A	88,068	12.39	1,091,163
11B	90,647	12.79	1,159,375
12D	0	13.17	0
12E	56,417	13.45	758,809
13B	11,668	14.05	163,935
14A	10,600	19.78	209,668
14B	27,000	20.14	534,780
14C	12,100	20.45	247,445
15A	15,700	25.94	407,258
16	7,700	36.47	280,819
17E	0	71.88	0
18A	2,000	74.33	148,660
19	7,000	76.03	532,210
19C	1,000	90.09	90,900
20A	2,000	77.58	155,160
20B	100	79.57	7,957

Table 6.3 Water Volume, Costs and Total Costs by Reach (continued)

Reach	Water Volume (AF)	Costs/AF	Total Costs
21	640	$ 80.54	51,546
22A	1,400	81.25	113,750
22B	39,200	100.46	3,983,032
23	0	100.89	0
24	932	105.89	98,689
26A	365,240	98.60	36,012,664
28G	0	102.92	0
28H	20,600	107.01	2,204,406
28J	0	121.37	0
29F	50	82.56	4,128
30	350,700	82.92	29,080,044
31A	89,500	26.29	2,352,955
33A	0	126.73	0
34	0	133.09	0
35	0	153.18	0

The total volume estimate for 1976 for the entire system is approximately 1.3M acre-feet. There are 37 reaches receiving this water at an average of 35,000 acre-feet each. The average cost per reach was calculated to be slightly more than $2M. So the average unit cost of an acre-foot of water delivered along the Aqueduct worked out to $57.72/Acre-Foot or approximately $60/Acre-Foot.

7. FORESTRY

7.1 Introduction and Summary

LANDSAT can assist in the management of United States forests in a variety of ways, including timber inventorying, hazard surveillance and damage assessment.

A quantitative study was performed of the benefits from timber inventorying alone, as applied to Forest Service lands in the South, the West and the Pacific Coast (ECON 1976). Improvement of information, applied to tree planting/harvesting decisions, was found to add $5 million annually in value to the timber harvest while maintaining all nontimber values.

Benefits result from the fact that LANDSAT imagery can be used as the primary classification source for a stratified sampling of timber. The Remote Sensing Research Program at Berkeley (RSRP 1974) has shown that this can yield a 10 percent gain in accuracy or a 44 percent cost savings in Forest Survey work in a typical western forest. This implies that the inventory cycle of National Forest lands could be changed from once in ten years to once in 5 to 6 years, while maintaining current standards of accuracy and current budget levels. By speeding up the inventory cycle, the information on which decisions are based--and the decisions themselves--show marked improvement.

7.2 Benefit Derivation

ECON, Inc. (1976b) has developed a model of Forest Service timber management which will permit the estimation of the impact of improved information on the decisions that forest managers make on tree-planting/timber-harvesting. These decisions are of long-term importance because overharvesting impairs the reproduction rate of a forest, while underharvesting leads to lower growth rates. The model recognizes that the Forest Service must also take nontimber values into account, because it is mandated to recognize the values of standing trees for purposes of aesthetics, recreation, soil conservation and wildlife habitats.

The focus of the model is on the intermediate level of planting/harvesting decisions, involving allocations of planting and harvesting between forests of several hundred thousand to a few million acres. This would be a "subregion" to the Forest Service, and is regarded as the level at which LANDSAT data would have the greatest impact.

The model characterizes "information" by two major characteristics: timeliness and accuracy.

Decision making is simulated using optimization techniques--a dynamic programming formulation is employed. Each timber demand region is separately optimized in terms of the values of the timber in its subregions.

Three components are of importance. These are as follows:

1. A value function, which ascribes values to outputs and decisions. Values from forests accrue from both the timber harvested and from the timber not harvested. The timber value can be estimated from market data. The nonharvested timber provides values such as those cited above. The existence of positive value for standing timber *per se* is evidenced by the fact that the dollar return for federal timber, and the timber growth rates themselves, fall below the market rate of interest. If strictly market factors were permitted complete domination, our National Forests would be liquidated, as is acknowledged by Forest Service personnel. Nontimber values

are assumed to persist in the future as in the past.

2. A state transformation. This describes how the forest inventory changes over time, as a function of region and volume of the standing trees, and the rate of harvesting. Tree growth data from the past are employed to derive the necessary constants.

3. An information descriptor. This describes the accuracy of knowledge of the standing timber volume at any time. This is a function of the accuracy of measurement of timber volume and growth, and the time elapsed since the last measurement. The mean value of the elapsed time since the last measurement, of course, depends on the frequency of measurements.

The model produces estimates of the total present value of the forest resource, region by region, as a function of

1. Accuracy of timber volume estimates
2. Accuracy of timber growth rate estimates
3. Accuracy of update of measurements.

Three Forest Service regions were considered--Southern Pine, Western Pine and the Pacific Coast. Smaller Forest Service holdings in the Northeast and midwest, and hardwood forests were not studied. Private forest holdings were not considered as major beneficiaries because of their current intensity of management.

The major assumptions employed are as follows:

1. The social decision-making mechanism (a Forest Service-Administration-Congress consortium) approximates optimal decision making, once all values, including the nontimber values, are considered.

2. Decisions are made on a region-by-region basis.

3. There exists approximate equivalence between NFS sales and harvests.

4. Current Forest Service capabilities are those characterized by the 'Forest Survey Handbook', which calls for a ten-year rotating inventory of all forest lands, with a mean accuracy of $\pm$ 5 percent of timber volume and timber growth in the South and $\pm$ 10 percent in the West.

Table 7.1 presents a listing of the data inputs which were used in the NFS Management model in order to estimate benefits. Sources of data used and methods of estimation are cited.

7.3 Results

The results of the application of this model to the Forest Service's National Forest System are summarized in Table 7.2. Annual benefits of \$5.9 million and \$7.2 million are shown for the LANDSAT-MSS and TM systems, respectively.

Notice that these LANDSAT systems have the capability of providing greater accuracy at equal costs and frequency <u>or</u> greater frequency at equal cost and accuracy. These capabilities have been documented by the Remote Sensing Research Program at University of California, Berkeley in a 1974 study in the Plumas National Forest in Northern California. There the Berkeley group reported that a 10 percent decrease in error or a 44 percent cost savings were possible by adding a LANDSAT-MSS system on to existing Forest Services practices. The 44 percent cost saving has been translated into a 40 percent increase in inventory frequency for use in ECON's benefit model. Attempts by RSRP to extend these results to the Sam Houston National Forest (Texas) in 1976 were unsuccessful and no advantage from the MSS system

Table 7.1 Inputs Used in Forestry Benefit Study

INPUT	SOURCE OF DATA USED	METHOD OF ESTIMATION
Regional elasticity of timber demand	Market and sales data from Forest Service and other demand studies	Regression
Elasticity of non-timber demand	NA*	Reasonable approximation based on observed public behavior
Timber growth rates by region	Forest Service	Regression
Current state of NFS Timber system	Forest Service	NA
Discount rate	Academic Literature	Consensus from other natural resource management studies
Variability of timber growth	Forest Service personnel	Consensus from discussions
Current NFS information capabilities	Forest Service	NA
Non-timber prices	Forest Service sales data	Use of NFS Management Model

* NA ≡ Not Applicable

Table 7.2 Estimated Annual Gross Benefits from LANDSAT-MSS and -TM Systems in National Forest Timber Sales Management[a]

Timber Demand Region	LANDSAT-MSS System[b]		LANDSAT-TM System[b]	
	From Increased Measurement Accuracy[c]	From Increased Frequency of Inventory[c]	From Increased Measurement Accuracy[c]	From Increased Frequency of Inventory[c]
	Gross Annual Benefits, Millions of 1975 Dollars			
Southern Pine	None	None	0.63	1.27
Western Pine	3.96	3.83	3.96	3.83
West Coast	1.97	1.69	1.97	1.69
Total	5.9		7.2	

[a] Estimated benefits based on softwood timber and volume and growth measurements only; see text.

[b] System capability inputs from NASA, based on RSRP 1974 and RSRP 1976.

[c] Benefits shown for increased accuracy and increased frequency are alternative benefits and are not additive. Benefits marked by underline are those used in calculating the total benefits.

could be shown due to the fact that the Southern Pine stands there were less structured than those of the Plumas NF. On these two studies, NASA has estimated that the 1974 study results apply to all western forests and that no benefit from LANDSAT-MSS can be shown in the South. NASA has further estimated that the increased spectral and spatial resolution of the TM system should be sufficient to extend the increased capabilities shown in the West to the Southern Pine region. The ECON results reported in Table 7.2 reflect these capability estimates.

In addition to the $5.9 million MSS and $7.2 million TM annual benefits cited above for the regional level Forest Service timber inventories, some benefits should be attainable at the level of individual forests, and from other federal lands such as those under the jurisdiction of the Bureau of Land Management, the Bureau of Indian Affairs, and the National Park Service. These additional benefits have not been quantified at this time.

Other LANDSAT forestry applications should also be of importance. These include surveillance of forests to detect areas of high fire hazard or susceptibility to pests or disease; or assessing the damage from fires, pests, disease, or floods. Although LANDSAT clearly is well adapted to these applications, the capabilities have not been thoroughly documented and benefit models have not been developed for them as yet.

8. LAND USE PLANNING AND MONITORING

8.1 Introduction and Summary

The land use planning and environmental monitoring applications of LANDSAT are extremely diverse, and represent at least $15 million and more likely $48 million in annual benefits. The lower value is based on the estimated cost of obtaining LANDSAT-equivalent land use data on a once-a-year basis for the entire United States; this is considered to be a very conservative statement of the actual requirement. The $48 million value is the estimated cost of obtaining such data four times annually, which is more likely to satisfy the differing seasonal requirements of the different users of the data.

Land use data of the type available from LANDSAT are useful as a basis for legislative and policy decisions, for project planning, for zoning and permit granting, for detection of unauthorized or conflicting uses, for research and assessment of current problems, and for early warnings of future problems. The user community consists of hundreds of federal, state, regional and local agencies, as well as academicians, planners, contractors and consultants. The user referred to here, of course, are additional to the users associated with the specific applications discussed in other chapters, such as agricultural crop information, oil and mineral exploration, water resources and forestry.

The land use planning-monitoring community has traditionally been forced to take data from diverse and often outdated sources, or else to incur the costs of aerial surveys. The use of existing data sources has proved to be very expensive, because of the labor required to select, combine, interpret and update the sources, and code the information in a usable form. Updating ordinarily requires searching records, performing site visits and reducing the results to the common format. Special purpose aerial surveys and interpretations of the resulting images are also expensive. Pooling of efforts is difficult to achieve.

LANDSAT's benefit derives from replacing these piecemeal efforts with a data product that is uniform, current and capable of automated interpretation. Its value can be assessed <u>at a minimum</u> as equal to the cost of obtaining such a product by the least cost system that would satisfy the combined needs of land use planning and monitoring agencies. This would be a national, airborne surveillance system, such as has been suggested from time to time by various informed observers, among them OMB (1972).

The benefits, \$15 to \$48 million per year, are based on the cost of operating such a hypothetical system, with the required frequency of total U.S. coverage--estimated in a later section to be from once to four times per year.

8.2 Derivation of Benefits

The system posed as the least cost alternative to LANDSAT as a land use data source is one based on the U-2 high-altitude reconnaissance aircraft. The U-2s are assumed to be equipped with instruments producing the same spectral bands and resolution as the LANDSAT Thematic Mapper, and to be based at five strategic places in the continental United States and Alaska. Their flights would be planned and coordinated so as to take advantage of good weather, with the objective of producing cloud-free imagery of all parts of the United States with a frequency of once per year at a minimum and four times per year at a maximum.

The aircraft system must be operated in certain ways to provide imagery comparable with LANDSAT imagery--some sidelap must be provided to compensate for flight path errors, the viewing angle must be within approximately 25° of the vertical, and the time of day of imaging must be within 1 to 2 hours of the time of LANDSAT passover. The exact rigidity of these restrictions is a function of the terrain steepness, and has been taken into account in computing aircraft system costs. It has also been necessary to make allowance for the time each aircraft loses in climbing to or descending from altitude and in cruising to the starting position for imaging, as well as the reflights that become necessary because of equipment malfunctions or cloud cover losses. Prior U-2 imaging experience has been useful in making the necessary adjustments. Aircraft are assumed to be operated up to 700 hours per year, in order to permit necessary scheduled and unscheduled maintenance. Existing U-2s are not assumed to be included in this program because of inadequate payload capabilities, but only enough U-2s are purchased to obtain the necessary imagery without exceeding the maximum yearly flying hours per aircraft.

The aircraft system cost elements are as recorded in Table 8.1. These figures are largely derived, as indicated, from NASA Ames Flight Center experience. The major exception is the data processing cost figure, which includes the cost of radiometric and geometric correction of the data, as well as land use classification and limited mosaicing of the images into useful scenes. The cost of this data processing was determined by a special study which took into account the hardware and software requirements for performing these functions for low and high data-rate aircraft systems.

Table 8.1 Aircraft System Cost Elements

	Values Used (1976 $)	Source of Data
CAPITAL COSTS*		
Aircraft	$9,000,000	Current Ames estimates are $7-10 million based on lot buys.
Sensors (per aircraft)	$1,000,000	Derived from Texas Instruments bid on Ames MSS procurement, modified upwards 4X for added requirements.
Set-Up Cost	$4,630,000 (5 bases)	Ames A/C Support Study (1973), inflated at 8% annually to 1976 and adjusted for #bases.
Set-Up Cost (per aircraft)	$ 310,000	
FIXED ANNUAL COSTS		
Bases	$ 610,000 (per aircraft)	Ames FY75 experience, inflated. A/C-related costs include fixed base costs. Costs based on 700 hour per year usage level.
Aircraft (per aircraft)		
VARIABLE ANNUAL COSTS		
Flying (per flight hour)	$ 1,510	Ames FY75 experience, inflated.
Data Processing (per data hour)	$ (3,000) (Correction only; classification considered same as for LANDSAT)	No reliable data source has been found; existing MSS experience based on experimental operation of 24-channel instrument flown at 10-12,000 feet.

* Annualized at 10% rate.

The special study was performed in a manner that makes these costs comparable with the LANDSAT data processing costs for purposes of computing net benefits.

The cost of operating a U-2 surveillance system are shown in Table 8.2. These figures are consistent with the unit costs shown in Table 8.1, and the attainable scheduling and operating efficiencies, reflight rates and rates of imaging new terrain.

Four scenarios are shown:

1. Annual coverage--summer months
2. Annual coverage--winter months
3. Semiannual coverage--summer and winter
4. Seasonal coverage.

The two cases of greatest interest are numbers 2 and 4. These represent the minimal versus the more adequate satisfaction of the data resource needs of the land use planning-monitoring community. The range of costs--and therefore the benefits from having the LANDSAT data instead--is $15 to $48 million annually.

8.3 Data Requirements of the Land Use Planning-Monitoring Community

As indicated above, it is essential to determine the frequency and timing of the demand for land use information by the land use planning and monitoring community in order to measure the benefits of LANDSAT data. Owing to the diffuseness of the user community, and some uncertainties regarding the classification capabilities of LANDSAT with the Thematic Mapper, it is difficult to characterize this demand precisely. Some factors are operative that permit us to estimate the upper and lower bounds of demand, however. A lower bound for demand may be taken as annual coverage of the terrain, preferably taken at a time of maximum visibility of features, such as after leaf-loss

Table 8.2 Aircraft System Annual Costs ($ Millions)

Scenario	Coverage	A/C Required	Capital Cost	Flight Cost	Data Cost	Total Cost
1	Once annually June, July, August	5	5.46	4.39	4.69	14.54
2	Once annually November - March	6	6.48	4.06	4.31	14.85*
3	Twice annually June - August, November - March	7	7.50	7.89	9.00	24.39
4	Four times annually June - August, September - November, December - February, March - May	14	14.65	15.26	18.05	47.96*

* Bounding cases for "minimum" and "adequate" land use coverage

in autumn, but before the first snows have fallen. This lower bound follows from several independent reasons:

1. ECON (1974) identified 25 separate statutory reporting functions, each representing an average annual coverage of about ten percent of the United States land surface. Taken together, and discounting for overlap, ECON concluded that a statutory requirement existed in 1974 for at least annual 100 percent coverage of the United States land surface.

2. Particular review functions of federal agencies, such as the review of environmental impact statements, wetlands development permits, or applications for variances from environmental pollution requirements, can only be conducted within the intent of the law if reasonably current data, not more than a year old, is employed.

3. The state and regional planning officials interviewed in connection with this study indicated that a year was typical time frame for most of their planning projects, and that data on land use should not be more than a year old at the time it is introduced into the studies, if at all possible.

At the opposite extreme, a case might be made for seasonal--four times a year--coverage requirements developing in the early 1980s as the full capabilities of the LANDSAT Thematic Mapper system become known. Such a demand for seasonal coverage need not imply that very many, or even one user, make use of all the data. Instead, seasonal coverage would provide each user with the capability to select the data taken at the time most appropriate to his own peculiar planning or monitoring need. Delineation of vegetative types is clearly done better during the green season, but man-made improvements are ordinarily seen better when leaves are off. Snow enhances the visibility of some features, but interferes with others. If seasonal coverage were provided, it seems likely that some users would make use of nearly every season of coverage.

For purposes of this study, therefore, we have assumed a range of demand between one and four times annually for total United States coverage. Benefits are calculated in accordance with these limits.

9. SOIL MANAGEMENT

9.1 Introduction and Summary

LANDSAT Follow-on is expected to contribute significantly to soil management by speeding the preparation of soil base maps, by observing the time and place of soil loss and by detecting the place and degree of soil nutrient deficiencies.

Of these benefits, however, only the first has been quantified. By reducing the cost and accelerating the production of soil base maps for the 1.3 billion acres not yet having such maps in the United States, annual cost savings of \$5.3 to \$8.8 million are anticipated throughout the 1980-1995 period. Further benefits, which are not quantified, will result from the earlier availability of the base maps. The base map program is discussed in the next section.

The benefits from observing soil loss and nutrient deficiencies are considered in Section 9.3, but estimates of dollar values are not yet available.

9.2 Soil Base Maps

As of July 1, 1975, the date of the most recent accurate figures, there were 1.352 billion acres or 59 percent of the United States for which no soil surveys had been completed. The Soil Conservation Survey is engaged in a 20-year program to provide soil base maps for the remainder of the United States.

LANDSAT can reduce the time needed to produce a soil survey by defining soil boundaries in the planning stages of a survey. J. B. Peterson (1976) of the Laboratory for Application of Remote Sensing at Purdue University has estimated that 1 to 1½ years can be saved from the normal 7 to 8 year period to perform a soil survey, with a proportionate reduction in cost. This amounts to a 12 to 21 percent reduction in the normal cost, which as of 1975, was $0.75 per acre.

Under the SCS's 20-year program, about 57 million acres enter the planning stage each year, and will continue to do so until 1995. The estimated annual savings are therefore 12 to 21 percent of the $43 million cost of performing soil surveys on these 57 million acres--or a $5.3 to $8.8 million annual benefit. We do not attempt to estimate the additional benefit of having the soil base maps available sooner than would be the case without LANDSAT, although it is worth noting that Klingbliel (1966) estimates that a soil survey repays its full cost within the first year after its completion.

9.3 Other Benefit Areas

9.3.1 Soil Loss Studies

The Department of Agriculture (1965) estimated the annual United States soil loss to be $1.6 billion during the period 1951-1960. At today's farm real estate values, such a rate of loss would be worth more than $5 billion. Soil conservation measures may have served to reduce this loss somewhat, but the losses must still exceed $1 billion annually.

The United States extends assistance in soil conservation in the form of technical extension services, tax deductions for conservation measures, cost sharing with landowners for specified conservation actions and government-funded research. These measures, in total, are estimated to cost several hundred million dollars per year.

LANDSAT is expected to increase the effectiveness of this program. Its capabilities include the ability to monitor sediment flow in waterways (Peterson, private communication). Experiments have not yet reached the point where benefits can be calculated, however.

9.3.2 Soil Nutrient Deficiencies

Deficiencies of nutrients in the soil cause crop production losses, relative to potential yields or quality. In one sorghum production area of 300,000 acres in Texas, Pennington (1976) has estimated that iron deficiencies cost $8.6 million in annual crop production.

The extent of deficiency must be known to determine the quality of added nutrient that will produce optimal returns. LANDSAT is of value in determining not only the presence, but also the extent and degree of deficiencies. Gaussman (1975), for example, has shown that LANDSAT can detect the presence and areal extent of iron chlorosis in sorghum, due to iron deficiency in the soil. Again, however, the experimental program has not yet progressed to the point that definite benefits can be calculated.

In summary, a definite annual benefit of at least $5.3 to $8.8 million can be attributed to LANDSAT's capability for reducing the cost of soil survey work--with strong indications that large additional benefits may result from LANDSAT's capabilities for detecting and measuring erosive soil loss and soil nutrient deficiencies.

10. NON-QUANTIFIED BENEFITS

10.1 Introduction and Summary

In earlier chapters, we discussed LANDSAT Follow-on in terms of areas of application where not only had capabilities been demonstrated, but the economic benefits could be quantified. These are minimum benefits for those areas, because the assumptions chosen were consistently conservative. Furthermore, in many instances the quantifiable part of the benefit appeared to understate the full picture of benefits by a large factor.

In this chapter, we cover additional areas of LANDSAT Follow-on application that seem certain to be important. In these areas either a full definition of capability or a satisfactory economic model of benefits is still to be developed. Nevertheless, some idea of the probable importance and likelihoods of benefits can be presented.

Out of many areas that have been cited in the remote sensing literature, just four are selected for brief discussion here. These are as follows:

- Rangeland Management
- Crop Pest Management
- Construction Siting
- Global Environment Monitoring

They will be discussed in the following sections.

10.2 Rangeland Management

LANDSAT offers the prospect of improved management practices for the private stockman and the manager of public rangelands. The following areas of benefit have been identified:

1. Assessing forage availability. The stockman and public land manager must determine when seasonal grazing may commence, the intensity of use, the requirements for supplemental feed and the time for removing stock to protect the range from overgrazing. LANDSAT can be useful in this function, provided that the Thematic Mapper demonstrates good capability for biomass measurement, to within ± 150 pounds per acre (Deering, 1976).

2. Deciding stocking levels for planning purposes. The private stockman and public manager must plan stocking levels well before a grazing season commences, so that bank financing, leases and other management arrangements can be made. This requires assessment of the range's typical carrying capacity, based on surveillance of range productivity over a period of several years. LANDSAT is well adapted to this.

3. Range improvement decisions. The stockman's primary means for controlling how the stock will utilize the range is by fencing and placement of water holes. Such capital improvements are expensive. The maximum benefit can be obtained only if the pattern of grazing is studied, and the fencing-waterhole layout is carefully planned. LANDSAT is readily able to show the grazing pattern and areas of over and underutilization of range for this purpose.

4. Detecting 'problem' rangelands. Rangeland that is consistently overgrazed will show a progressive change in species composition--from desirable to less desirable grasses, weeds, and eventually shrubs and bare ground. When this is observed on public lands, shrub clearance, seeding, changes in grazing practices and stock allotments, etc. are called for. When private lands are involved, endeavors should be made by the Soil Conservation Service to make the owner aware of alternatives to consider, and public help that is available. LANDSAT is useful in detecting these 'problem' range areas, since it can detect significant changes in species composition (Berkeley, 1976).

5. Trespass control. The public land manager is faced with the problem of preventing grazing without a license or beyond the terms of a license--yet he has very few enforcement officers to cover millions of acres. Although LANDSAT cannot prove a violation, it can be of great use in finding places of likely violations so that the limited enforcement resources can be programmed more efficiently.

10.3 Crop Pest Management

LANDSAT should provide substantial benefits in crop pest management, based on the enormous quantity of losses--estimated at over $4 billion in 1973 (ECON, 1974)--and the apparent detectability of pest-related information.

Insufficient work has been done to determine definite satellite capabilities, or the manner of using the information to the growers' best advantage. Investigations, such as the study of the alfalfa weevil at Purdue, are expected to remedy this lack in the near future.

Despite the absence of definitive work at this time it should be possible to determine the areal extent, severity of damage, and rate of movement of the zones of affliction, insofar as the early-phase damage is visible in the plant foliage. It should also be possible to observe vegetation that is under stress from drought or from excessively cool, warm, or moist conditions, and therefore more than usually susceptible to disease.

For the LANDSAT data to be of maximum utility to growers and agricultural advisors, it should fit into eco-system models that predict the rate of development of pests as a function of the initial insect population levels, plant condition levels, and weather. Whether the LANDSAT-generated information is processed by a model or furnished directly to growers, it would be useful in determining the nature and timing of control activities.

Benefits from more accurate programming of pest control activities include the following:

1. Minimizing costs of pesticide and costs of application
2. Minimizing the rate of development of resistance to the pesticide
3. Minimizing damage to the natural predators of the target pests
4. Minimizing environmental hazards to humans.

At this state of knowledge, however, the magnitude of the expected benefits cannot be quantified.

10.4 Construction Siting

LANDSAT's capability for detecting fractures in the earth's surface can produce major benefits in the evaluation and selection of construction sites.

Fractures indicate structural weaknesses that are of great importance in locating power plants, dams, mine tunnels, and roadways.

Nuclear power plants, for example, must be located where there is minimal risk of earth movement. Fractures indicate the danger areas of future earth movement by showing where the earth movements of hundreds or thousands of years past have been concentrated. Seismic records, which generally extend over only a few decades, are far from adequate for this purpose.

Dams are susceptible not only to earth movements but to underground fissures that may cause undermining, leakage, and structural weakening. Such causes are believed responsible for the Teton Dam failure in Idaho.

Mine tunnels are susceptible to cave-ins, and it is believed that fracture patterns indicate the layouts that may be safest. In 1975 there were 61 fatalities that occurred due to roof collapses of underground mines or high-wall collapses in open pit mines, some of which might have been prevented by improved mine layouts.

Finally, highways are very susceptible to landslides, which frequently follow fracture lines or other signs of instability detectable from a satellite.

LANDSAT is not unique in its ability to detect fractures in the earth's surface, but it <u>shows some fractures not observable from aircraft</u>--primarily those that are long in extent but very subtly marked. The Thematic Mapper is expected to show many features not already shown by LANDSAT 1 and 2;

SKYLAB, with a very similar resolution shows up to five times as many fractures as LANDSAT 1 and 2 in the limited areas where good SKYLAB imagery has been available.

In conclusion, the prevention of serious errors in siting of major facilities requires the use of all sources of information. LANDSAT, with the Thematic Mapper, may be expected to contribute a valuable component of this effort.

10.5 Global Environmental Monitoring

Despite major changes at work in the world's environment--changes affecting the atmosphere, the seas, the forests and wildlife habitats of the world--no continuous record today exists to document the changes. LANDSAT 2 and 3 have limited lifetimes, and do not report data for the oceans or for some critical land areas. Other satellites are restricted in function or location. Only the LANDSAT Follow-on program offers the completeness and continuity of coverage needed to perform time-series studies on the global environment.

The importance of such studies should be evident. The conversion of the Sahel from grazing land to desert within the last 20 years would have been noted sooner--and preventive measures possibly begun--if LANDSAT images had been available. Pollution of the seas is increasing dramatically--as attested by airline pilots and sailing captains--but no record is compiled of the sources, movements, or dispersal of the pollution. Forests are converted to settlements, ranges plowed under, and roads built into virgin tundra, all without records that would help scientists and planners to cope with the problems.

LANDSAT's value in providing such an archive is incapable of estimation--but one may be sure that it is large, and that the value will compound as the length of the record grows and new uses are found for employing it.

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